Appendix G

Human Exposure Factors

Exposure factors are data that quantify human behavior patterns (e.g., ingestion rates of beef and fruit) and characteristics (e.g., body weight) that affect their exposure to environmental contaminants. These data can be used to construct realistic assumptions concerning an individual's exposure to and subsequent intake of a contaminant in the environment. The exposure factors data also enable the U.S. Environmental Protection Agency (EPA) to differentiate the exposures of individuals who have different lifestyles (e.g., a resident vs. a farmer and a child vs. an adult). The derivation and values used for the human exposure factors in this risk assessment are described here and the exposure factors selected for the probabilistic analyses are presented.

G.1 Exposure Parameters Used in Deterministic Analysis

For most exposure factors parameters, data used in the deterministic analysis were obtained from the *Exposure Factors Handbook* or EFH (U.S. EPA, 1997a, 1997b, 1997c). Central tendency values were represented by the 50th percentile (median) values. High-end values were represented by the 90th percentile values; exposure duration was the only exposure factor for which high-end values were used. The exposure factors parameters used in the deterministic analysis are summarized in Table G-1.

The central tendency and high-end values (9 and 30 years, respectively) used for the exposure duration of adult residents and fishers were EPA-recommended values from the EFH (Table 15-176, U.S. EPA, 1997c). Exposure duration for the child resident (5 and 13 years for central tendency and high-end values, respectively) was based on the data for 3-year-olds (the average child start age occurring between ages 1 and 6) (Table 15-168, U.S. EPA, 1997c). Exposure duration for the adult and child farmer (10 and 48.3 years for central tendency and high-end values, respectively) was based on farm residence time data (Table 15-164, U.S. EPA, 1997c).

For adults (noncancer and cancer risk analyses), 50th percentile exposure factor values (e.g., food intake rates) for the various adult receptors (resident, fisher, or farmer) were used for both the central tendency and high-end deterministic risk analyses. However, different central tendency and high-end exposure factor values were developed for the cancer and noncancer risk analyses in children. The values were time-weighted averages over the exposure duration of a

Table G-1. Summary of Exposure Parameters used in Deterministic Analysis

Receptor/Parameter	CT Analysis	HE Analysis	Units
Adult Farmer			
Body weight	6.93E+01	NV	kg
Consumption rate - beef	1.64E+00	NV	g/kg-d
Consumption rate - exposed fruits	1.30E+00	NV	g/kg-d
Consumption rate - exposed vegetables	1.38E+00	NV	g/kg-d
Consumption rate - milk	1.21E+01	NV	g/kg-d
Consumption rate - protected fruits	2.13E+00	NV	g/kg-d
Consumption rate - root vegetables	8.83E-01	NV	g/kg-d
Consumption rate - soil	5.00E-05	NV	kg/d
Exposure duration	1.00E+01	NV	yr
Inhalation rate	1.33E+01	NV	m^3/d
Adult Fisher			
Body weight	6.93E+01	NV	kg
Consumption rate - fish	2.00E+00	NV	g/d
Consumption rate - soil	5.00E-05	NV	kg/d
Exposure duration	9.00E+00	NV	yr
Inhalation rate	1.33E+01	NV	m^3/d
Adult Resident			
Body weight	6.93E+01	NV	kg
Consumption rate - drinking water	1.25E+03	NV	mL/d
Consumption rate - soil	5.00E-05	NV	kg/d
Exposure duration[a]	9.00E+00	NV	yr
Inhalation rate	1.33E+01	NV	m^3/d

(continued)

Table G-1. (continued)

Receptor/Parameter	CT Analysis	HE Analysis	Units
Child Farmer - Cancer			
Body weight	2.80E+01 [b]	5.89E+01 [c]	kg
Consumption rate - beef	2.05E+00 [b]	1.71E+00 [c]	g/kg-d
Consumption rate - exposed fruits	1.27E+00 [b]	1.19E+00 [c]	g/kg-d
Consumption rate - exposed vegetables	8.89E-01 [b]	1.17E+00 [c]	g/kg-d
Consumption rate - milk	1.41E+01 [b]	1.15E+01 [c]	g/kg-d
Consumption rate - protected fruits	2.23E+00 [b]	2.02E+00 [c]	g/kg-d
Consumption rate - root vegetables	5.76E-01 [b]	7.73E-01 [c]	g/kg-d
Consumption rate - soil	6.50E-05 [b]	5.31E-05 [c]	kg/d
Exposure duration	1.00E+01 [b]	4.83E+01 [c]	yr
Inhalation rate	1.08E+01 [b]	1.29E+01 [c]	m^3/d
Child Farmer - Noncancer			
Body weight	1.53E+01	NV	kg
Consumption rate - beef	2.11E+00	NV	g/kg-d
Consumption rate - exposed fruits	1.82E+00	NV	g/kg-d
Consumption rate - exposed vegetables	1.46E+00	NV	g/kg-d
Consumption rate - milk	2.15E+01	NV	g/kg-d
Consumption rate - protected fruits	2.34E+00	NV	g/kg-d
Consumption rate - root vegetables	6.86E-01	NV	g/kg-d
Consumption rate - soil	1.00E-04	NV	kg/d
Exposure duration	1.00E+00	NV	yr
Inhalation rate	7.60E+00	NV	m^3/d

(continued)

Table G-1. (continued)

Receptor/Parameter	CT Analysis	HE Analysis	Units
Child Resident - Cancer			
Body weight	2.10E+01 [b]	3.47E+01 [c]	kg
Consumption rate - drinking water	6.62E+02 [b]	7.47E+02 [c]	mL/d
Consumption rate - soil	8.00E-05 [b]	6.15E-05 [c]	kg/d
Exposure duration	5.00E+00 [b]	1.30E+01 [c]	yr
Inhalation rate	9.28E+00 [b]	1.15E+01 [c]	m^3/d
Child Resident - Noncancer			
Body weight	1.53E+01	NV	kg
Consumption rate - drinking water	6.17E+02	NV	mL/d
Consumption rate - soil	1.00E-04	NV	kg/d
Exposure duration	1.00E+00	NV	yr
Inhalation rate	7.60E+00	NV	m^3/d

[a] Adult resident exposure duration from EFH Table 15-176 (U.S. EPA, 1997c).

[b] Child (cancer) intake rates and body weights are time-weighted averages based on CT exposure duration.

[c] Child (cancer) intake rates and body weights are time-weighted averages based on HE exposure duration.

NV = not varied. Note: only exposure duration or parameters sensitive to exposure duration (i.e., exposure factors for child cancer) were varied.

child for carcinogens. Carcinogenic risk is assessed over the entire exposure duration because cancer risk is generally described in terms of excess probabilities of developing cancer over a lifetime. For the child cancer risk analysis, a time-weighted average of 50^{th} percentile exposure factors was used based on the 50^{th} percentile exposure duration for the central tendency risk analysis and on the 90^{th} percentile exposure duration for the high-end risk analysis. Noncarcinogens were based on youngest cohort defined by the start age because noncancer risk is evaluated annually. For the noncancer risk analysis for children, the 50^{th} percentile exposure factor values for 1 to 5-yr-olds were used for both the central tendency and high-end analyses.

G.2 Exposure Parameters Used in Probabilistic Analysis

G.2.1 Introduction

The general methodology for collecting human exposure data for the probabilistic analysis relied on the *Exposure Factors Handbook* (U.S. EPA, 1997a, 1997b, 1997c), which was used in one of three ways:

1. When EFH percentile data were adequate (most input variables), maximum likelihood estimation was used to fit selected parametric models (gamma, lognormal, Weibull, and generalized gamma) to the EFH data. The chi-square measure of goodness of fit was then used to choose the best distribution. Parameter uncertainty information (e.g., for averages, standard deviations) also was derived using the asymptotic normality of the maximum likelihood estimate or a regression approach.

2. For a few variable conditions when percentile data were not adequate for statistical model fitting, models were selected on the basis of results for other age cohorts or, if no comparable information was available, by assuming lognormal as a default distribution and reasonable coefficients of variation (CVs).

3. Other variables for which data were not adequate for either 1 or 2 above were fixed at EFH-recommended mean values or according to established EPA policy.

Table G-2 summarizes all of the parameters used in the probabilistic analysis. Both fixed variables and the values used to define distributed data are provided.

G.2.2 Exposure Parameter Distribution Methodology

Exposure parameter distributions were developed for use in the Monte Carlo analysis. For most variables for which distributions were developed, exposure factor data from the EFH were analyzed to fit selected parametric models (i.e., gamma, lognormal, Weibull). Steps in the development of distributions included preparing data, fitting models, assessing fit, and preparing parameters to characterize distributional uncertainty in the model inputs.

For many exposure factors, EFH data include sample sizes and estimates of the following parameters for specific receptor types and age groups: mean, standard deviation, standard error, and percentiles corresponding to a subset of the following probabilities–0.01, 0.02, 0.05, 0.10, 0.15, 0.25, 0.50, 0.75, 0.85, 0.90, 0.95, 0.98, and 0.99. These percentile data were used as a basis for fitting distributions where available. Although in no case are all of these percentiles actually provided for a single factor, seven or more are typically present in the EFH data. Therefore, using the percentiles is a fuller use of the available information than simply fitting based on the method of moments (e.g., selecting models that agree with the data mean and standard deviation). For some factors, certain percentiles were not used in the fitting process because sample sizes were too small to justify their use. Percentiles were used only if at least one data point was in the tail of the distribution. If the EFH data repeated a value across several adjacent percentiles, only one

Table G-2. Summary of Exposure Parameters used in Probabilistic Analysis

Parameter	Units	Variable Type	Constants	Mean (or shape)	Std Dev (or scale)	Minimum	Maximum	Reference
Averaging time for carcinogens	yr	Constant	7.00E+01					U.S. EPA (1989) (RAGS)
Body weight (adult)	kg	Lognormal		7.12E+01	1.33E+01	1.50E+01	3.00E+02	U.S. EPA (1997a); Tbl 7-2, 7-4, 7-5
Body weight (child 1)	kg	Lognormal		1.55E+01	2.05E+00	4.00E+00	5.00E+01	U.S. EPA (1997b); Tbl 7-3, 7-6, 7-7
Body weight (child 2)	kg	Lognormal		3.07E+01	5.96E+00	6.00E+00	2.00E+02	U.S. EPA (1997a); Tbl 7-3, 7-6, 7-7
Body weight (child 3)	kg	Lognormal		5.82E+01	1.02E+01	1.30E+01	3.00E+02	U.S. EPA (1997a); Tbl 7-3, 7-6, 7-7
Consumption rate: beef (adult farmer)	g WW/kg-d	Lognormal		2.50E+00	2.69E+00	0.00E+00	2.30E+01	U.S. EPA (1997b); Tbl 13-36
Consumption rate: beef (child 1 farmer)	g WW/kg-d	Lognormal		3.88E+00	4.71E+00	0.00E+00	3.60E+01	U.S. EPA (1997b); Tbl 13-36
Consumption rate: beef (child 2 farmer)	g WW/kg-d	Lognormal		3.88E+00	4.71E+00	0.00E+00	3.60E+01	U.S. EPA (1997b); Tbl 13-36
Consumption rate: beef (child 3 farmer)	g WW/kg-d	Gamma		2.47E+00	7.10E-01	0.00E+00	1.00E+01	U.S. EPA (1997b); Tbl 13-36
Consumption rate: exposed fruit (child 1 farmer)	g WW/kg-d	Gamma		1.43E+00	1.58E+00	0.00E+00	1.60E+01	U.S. EPA (1997b); Tbl 13-61
Consumption rate: exposed fruit (child 2 farmer)	g WW/kg-d	Lognormal		2.78E+00	5.12E+00	0.00E+00	3.60E+01	U.S. EPA (1997b); Tbl 13-61
Consumption rate: exposed fruit (child 3 farmer)	g WW/kg-d	Lognormal		1.54E+00	2.44E+00	0.00E+00	1.80E+01	U.S. EPA (1997b); Tbl 13-61
Consumption rate: exposed fruit (farmer)	g WW/kg-d	Lognormal		2.36E+00	3.33E+00	0.00E+00	3.10E+01	U.S. EPA (1997b); Tbl 13-61
Consumption rate: exposed vegetables (adult farmer)	g WW/kg-d	Lognormal		2.38E+00	3.50E+00	0.00E+00	2.60E+01	U.S. EPA (1997b); Tbl 13-63
Consumption rate: exposed vegetables (child 1 farmer)	g WW/kg-d	Gamma		9.70E-01	2.62E+00	0.00E+00	2.10E+01	U.S. EPA (1997b); Tbl 13-63
Consumption rate: exposed vegetables (child 2 farmer)	g WW/kg-d	Lognormal		1.64E+00	3.95E+00	0.00E+00	2.70E+01	U.S. EPA (1997b); Tbl 13-63
Consumption rate: exposed vegetables (child 3 farmer)	g WW/kg-d	Gamma		9.10E-01	1.19E+00	0.00E+00	1.10E+01	U.S. EPA (1997b); Tbl 13-63
Consumption rate: fish (adult)	g/d	Lognormal		6.48E+00	1.99E+01	0.00E+00	1.50E+03	U.S. EPA (1997b); Tbl 10-64

(continued)

Table G-2. (continued)

Parameter	Units	Variable Type	Constants	Mean (or shape)	Std Dev (or scale)	Minimum	Maximum	Reference
Consumption rate: milk (adult farmer)	g WW/kg-d	Weibull		1.25E+00	1.75E+01	0.00E+00	1.11E+02	U.S. EPA (1997b); Tbl 13-28
Consumption rate: milk (child 1 farmer)	g WW/kg-d	Weibull		1.70E+00	2.65E+01	0.00E+00	1.33E+02	U.S. EPA (1997b); Tbl 11-2
Consumption rate: milk (child 2 farmer)	g WW/kg-d	Weibull		1.56E+00	1.48E+01	0.00E+00	7.90E+01	U.S. EPA (1997b); Tbl 11-2
Consumption rate: milk (child 3 farmer)	g WW/kg-d	Weibull		1.14E+00	6.52E+00	0.00E+00	4.50E+01	U.S. EPA (1997b); Tbl 11-2
Consumption rate: protected fruit (child 1 farmer)	g WW/kg-d	Lognormal		6.50E+00	1.59E+01	0.00E+00	1.08E+02	U.S. EPA (1997b); Tbl 13-62
Consumption rate: protected fruit (child 2 farmer)	g WW/kg-d	Lognormal		6.50E+00	1.59E+01	0.00E+00	1.08E+02	U.S. EPA (1997b); Tbl 13-62
Consumption rate: protected fruit (child 3 farmer)	g WW/kg-d	Lognormal		2.91E+00	6.39E+00	0.00E+00	4.40E+01	U.S. EPA (1997b); Tbl 13-62
Consumption rate: protected fruit (farmer)	g WW/kg-d	Lognormal		6.67E+00	1.77E+01	0.00E+00	1.20E+02	U.S. EPA (1997b); Tbl 13-62
Consumption rate: root vegetables (child 1 farmer)	g WW/kg-d	Lognormal		2.31E+00	6.05E+00	0.00E+00	4.10E+01	U.S. EPA (1997b); Tbl 13-65
Consumption rate: root vegetables (child 2 farmer)	g WW/kg-d	Weibull		6.80E-01	1.06E+00	0.00E+00	1.50E+01	U.S. EPA (1997b); Tbl 13-65
Consumption rate: root vegetables (child 3 farmer)	g WW/kg-d	Weibull		8.40E-01	9.10E-01	0.00E+00	9.00E+00	U.S. EPA (1997b); Tbl 13-65
Consumption rate: root vegetables (farmer)	g WW/kg-d	Lognormal		1.45E+00	2.06E+00	0.00E+00	1.50E+01	U.S. EPA (1997b); Tbl 13-65
Event frequency (shower)	event/d	Constant	1.00E+00					U.S. EPA (1997c); Tbl 15-176
Exposure duration (adult resident)	yr	Weibull		1.34E+00	1.74E+01	1.00E+00	5.00E+01	U.S. EPA (1999) (ACS)
Exposure duration (child)	yr	Weibull		1.32E+00	7.06E+00	1.00E+00	5.00E+01	U.S. EPA (1999) (ACS)
Exposure duration (farmer)	yr	Gamma		6.07E-01	2.98E+01	1.00E+00	5.00E+01	U.S. EPA (1997c); Tbl 15-163, 15-164
Exposure frequency (adult resident)	d/y	Constant	3.50E+02					U.S. EPA (1991)
Fraction home caught: fish	Fraction	Constant	3.25E-01					U.S. EPA (1997b); Tbl 13-71

(continued)

Table G-2. (continued)

Parameter	Units	Variable Type	Constants	Mean (or shape)	Std Dev (or scale)	Minimum	Maximum	Reference
Fraction home-produced: beef (farmer)	Fraction	Constant	4.85E-01					U.S. EPA (1997b); Tbl 13-71
Fraction contaminated: drinking water	Fraction	Constant	1.00E+00					U.S. EPA Policy
Fraction home-produced: milk (farmer)	Fraction	Constant	2.54E-01					U.S. EPA (1997b); Tbl 13-71
Fraction contaminated: soil	Fraction	Constant	1.00E+00					U.S. EPA Policy
Fraction homegrown: exposed fruit (farmer)	Fraction	Constant	3.28E-01					U.S. EPA (1997b); Tbl 13-71
Fraction homegrown: exposed vegetables (farmer)	Fraction	Constant	4.20E-01					U.S. EPA (1997b); Tbl 13-71
Fraction homegrown: protected fruit (farmer)	Fraction	Constant	3.00E-02					U.S. EPA (1997b); Tbl 13-71
Fraction homegrown: root vegetables (farmer)	Fraction	Constant	1.73E-01					U.S. EPA (1997b); Tbl 13-71
Fraction of fish consumed that is trophic level 3 (T3) fish	Fraction	Constant	3.60E-01					U.S. EPA (1997b); Tbl 10-66
Fraction of fish consumed that is trophic level 4 (T4) fish	Fraction	Constant	6.40E-01					U.S. EPA (1997b); Tbl 10-66
Ingestion rate: drinking water (adult resident)	mL/d	Gamma		3.88E+00	3.57E+02	1.04E+02	1.10E+04	U.S. EPA (1997a); Tbl 3-6
Ingestion rate: drinking water (child 1 resident)	mL/d	Gamma		2.95E+00	2.37E+02	2.60E+01	3.84E+03	U.S. EPA (1997a); Tbl 3-6
Ingestion rate: drinking water (child 2 resident)	mL/d	Gamma		3.35E+00	2.35E+02	3.40E+01	4.20E+03	U.S. EPA (1997a); Tbl 3-6
Ingestion rate: drinking water (child 3 resident)	mL/d	Gamma		2.82E+00	3.42E+02	3.30E+01	5.40E+03	U.S. EPA (1997a); Tbl 3-6
Ingestion rate: soil (adult resident)	kg/d	Constant	5.00E-05					U.S. EPA (1997a); Tbl 4-23
Ingestion rate: soil (child 1 resident)	kg/d	Lognormal		1.00E-04	1.50E-04	5.00E-07	3.00E-02	U.S. EPA (1997a); Tbl 4-23
Ingestion rate: soil (child 2 resident)	kg/d	Constant	5.00E-05					U.S. EPA (1997a); Tbl 4-23
Ingestion rate: soil (child 3 resident)	kg/d	Constant	5.00E-05					U.S. EPA (1997a); Tbl 4-23

(continued)

Table G-2. (continued)

Parameter	Units	Variable Type	Constants	Mean (or shape)	Std Dev (or scale)	Minimum	Maximum	Reference
Inhalation (breathing) rate (adult resident)	m^3/d	Lognormal		1.33E+01	3.99E+00	1.00E+00	5.00E+01	U.S. EPA (1997a), U.S. EPA (2000)
Inhalation (breathing) rate (child 1 resident)	m^3/d	Lognormal		7.55E+00	3.78E+00	1.00E+00	4.00E+01	U.S. EPA (1997a), U.S. EPA (2000)
Inhalation (breathing) rate (child 2 resident)	m^3/d	Lognormal		1.18E+01	3.53E+00	1.00E+00	4.50E+01	U.S. EPA (1997a), U.S. EPA (2000)
Inhalation (breathing) rate (child 3 resident)	m^3/d	Lognormal		1.40E+01	4.20E+00	1.00E+00	5.50E+01	U.S. EPA (1997a), U.S. EPA (2000)
Shower time	min	Gamma		2.83E+00	5.89E+00	1.00E+00	6.00E+01	U.S. EPA (1997c); Tbl 15-21

value (the most central or closest to the median) was used in most cases (e.g., if both the 98th and 99th percentiles had the same value, only the 98th value was used).

The EFH does not use standardized age cohorts across exposure factors. Different exposure factors have data reported for different age categories. Therefore, to obtain the percentiles for fitting the four standardized age cohorts (i.e., ages 1 to 5, 6 to 11, 12 to 19, and more than 20), each EFH cohort-specific value for a given exposure factor was assigned to one of these four cohorts. When multiple EFH cohorts fit into a single cohort, the EFH percentiles were averaged within each cohort (e.g., data on 1- to 2- and 3- to 5-year-olds were averaged for the 1- to 5-year old cohort). If sample sizes were available, weighted averages were used, with weights proportional to sample sizes. If sample sizes were not available, equal weights were assumed (i.e., the percentiles were simply averaged).

Because the EFH data are always positive and almost always skewed to the right (i.e., have a long right tail), three two-parameter probability models commonly used to characterize such data (gamma, lognormal, and Weibull) were selected. In addition, a three-parameter model (generalized gamma) was used that unifies them[1] and allows for a likelihood ratio test of the fit of the two-parameter models. However, only the two-parameter models were selected for use in the analysis because the three-parameter generalized gamma model did not significantly improve the goodness of fit over the two-parameter models. This simple setup constitutes a considerable improvement over the common practice of using a lognormal model in which adequate EFH data were available to support maximum likelihood estimation. However, in a few cases (soil ingestion and inhalation rate), data were not adequate to fit a distribution, and the lognormal model was assumed as the default.

Lognormal, gamma, Weibull, and generalized gamma distributions were fit to each factor data set using maximum likelihood estimation (Burmaster and Thompson, 1998). When sample sizes were available, the goodness of fit was calculated for each of the four models using the chi-square test (Bickel and Doksum, 1977). When percentile data were available but sample sizes were unknown, a regression F-test for the goodness of fit against the generalized gamma model was used. For each of the two-parameter models, parameter uncertainty information (i.e., mean, standard deviation, scale, and shape) was provided as parameter estimates for a bivariate normal distribution that could be used for simulating parameter values (Burmaster and Thompson, 1998). The information necessary for such simulations includes estimates of the two model parameters, their standard errors, and their correlation. To obtain this parameter uncertainty information, the asymptotic normality of the maximum likelihood estimate (Burmaster and Thompson, 1998) was used when sample sizes were available, and a regression approach was used when sample sizes were not available (Jennrich and Moore, 1975; Jennrich and Ralston, 1979). In either case, uncertainty can be expressed as a bivariate normal distribution for the model parameters.

This section describes how stochastic or distributed input data for each exposure factor were collected and processed. Section G.2.3 discusses fixed parameters. Section G.2.4 describes, for each exposure factor, the EFH data used to develop the distributions, along with

[1] Gamma, Weibull, and lognormal distributions are all special cases of the generalized gamma distribution.

the final distributional statistics. Section G.2.5 describes minimums and maximums. Two summary tables provided at the end of this appendix (Tables G-18 and G-19) present the final (raw) EFH data used to develop each exposure factor distribution used and the models selected (i.e., lognormal, Weibull, or gamma) and estimated means and standard deviations for each of the two-parameter models fit to the exposure factors data.

G.2.3 Fixed Parameters

Certain parameters were fixed, based on central tendency values from the best available source (usually *Exposure Factors Handbook* recommendations), either because no variability was expected or because the available data were not adequate to generate distributions. Fixed (constant) parameters are shown in Table G-3 along with the value selected for the risk analysis and data source. These constants include variables for which limited or no percentile data were provided in the EFH: exposure frequency, showering frequency, and fraction contaminated for the various media and foodstuffs. Most of these values were extracted directly from the EFH. The fraction contaminated for various foodstuffs was assumed to be equivalent to the fraction of household food intake that is attributed to home-produced forms of the food items evaluated (Table 13-71, U.S. EPA, 1997b). The fraction of consumed trophic level 3 (T3) and trophic level 4 (T4) fish was determined from data in Table 10-66 of the EFH (U.S. EPA, 1997b), which contains the only fish consumption data reported in the handbook with an adequate species breakdown to make this distinction. When evaluating carcinogens, total dose is averaged over the lifetime of the individual, assumed to be 70 years.

Table G-3. Summary of Human Exposure Factor Data Used in Modeling: Constants

Description	Units	Average	Source
Fraction homegrown: exposed fruit (farmer)	Fraction	0.328	EFH, Table 13-71
Fraction homegrown: exposed vegetables (farmer)	Fraction	0.42	EFH, Table 13-71
Fraction homegrown: protected fruit (farmer)	Fraction	0.03	EFH, Table 13-71
Fraction homegrown: root vegetables (farmer)	Fraction	0.173	EFH, Table 13-71
Fraction home-raised: beef (farmer)	Fraction	0.485	EFH, Table 13-71
Fraction home-produced: milk (farmer)	Fraction	0.254	EFH, Table 13-71
Fraction home caught: fish (recreational fisher)	Fraction	0.325	EFH, Table 13-71
Fraction of trophic level 3 (T3) fish consumed	Fraction	0.36	EFH, Table 10-66
Fraction of trophic level 4 (T4) fish consumed	Fraction	0.64	EFH, Table 10-66
Fraction contaminated: soil	Fraction	1	EPA policy
Fraction contaminated: drinking water	Fraction	1	EPA policy
Exposure frequency (adult resident, fisher, farmer; child resident, farmer)	d/yr	350	EPA policy
Averaging time for carcinogens (adult resident, fisher, farmer; child resident, farmer)	yr	70	U.S. EPA, 1989, RAGS
Ingestion rate: soil (adult, 6- to 11-yr-old child, 12- to 19-yr-old child)	kg/d	5.0E-5	EFH, Table 4-23

Source: EFH (U.S. EPA, 1997a, 1997b, 1997c)

The fraction contaminated for soil and drinking water was assumed to be 1 (i.e., all soil and drinking water available for consumption at a site is potentially contaminated), with actual concentrations depending on fate and transport model results. Thus, households for which the drinking water pathway was analyzed were assumed to get 100 percent of their drinking water from groundwater. Exposure frequency was set to 350 days per year in accordance with EPA policy, assuming that residents take an average of 2 weeks' vacation time away from their homes each year.

G.2.4 Variable Parameters

G.2.4.1 Soil Ingestion. Table G-4 presents soil ingestion data and distributions. Mean soil ingestion rates were cited as 100 mg/d for children (400 mg/d = upper percentile), 200 mg/d for children (conservative estimate), 50 mg/d for adults, and 10 g/d for pica children (Table 4-23, U.S. EPA, 1997a). No percentile data were recommended for use in the EFH. The lognormal model was used for soil consumption for 1- to 5-yr-olds. Parameter estimates were obtained by assuming the coefficients of variation (CV) = 0.5, 1, and 1.5. Population standard deviations based on a CV of 1.5 were used for the analysis. Adult data were used for the 6- to 11- and 12- to 19-yr-old variables. The soil ingestion rates for the adult and 6- to 11- and 12- to 19-yr-old receptors were not varied for the probabilistic analysis. The fraction of soil contaminated was assumed to be 1 (in accordance with EPA policy).

During a Peer Review Workshop that discussed revisions to a draft of the Exposure Factors Handbook dated Sept. 1995, the expert reviewers noted that "In qualitative terms, the actual distribution of soil ingestion in children is likely to be skewed, with many persons at the low end and a few at the high end. Members of the work group, however, have little confidence in current quantitative knowledge about the shape of the distribution" (U.S. EPA, 1996). The shape of this distribution should therefore be considered an uncertainty in this risk analysis.

Table G-4. Soil Ingestion Data and Distributions

EFH Data						
Age Cohort	**Data Mean (mg/d)**	**Distribution**	**Pop-Estd Mean (mg/d)[a]**	**Pop-Estd SDev (CV=0.5)**	**Pop-Estd SDev (CV=1)**	**Pop-Estd SDev (CV=1.5)[a]**
1-5	100	Lognormal	100	50	100	150
6-11	ND	Constant	50			
12-19	ND	Constant	50			
Adult	50	Constant	50			

Pop-Estd = Population-estimated; SDev = Standard deviation.
[a] Distributions used in risk assessment.

G.2.4.2 Exposed Fruit Consumption. Table G-5 presents exposed fruit consumption data. Data for consumption of homegrown exposed fruit were obtained from Table 13-61 of the

EFH (U.S. EPA, 1997b). Data (in g WW/kg-d) were presented by age groups and for farmers (adults). For the 1- to 5-yr old age group, data were only available for those ages 3 to 5 years (not available for 1- to 2-yr-olds); therefore, these data were used for the entire 1- to 5-yr-old age group. Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model. The fraction of exposed fruit intake that is home-produced is 0.328 for households that farm (Table 13-71, U.S. EPA, 1997b).

Table G-5. Exposed Fruit Consumption Data and Distributions

EFH Data – (g WW/kg-d)													Distributions		
Age Cohort	N	Data Mean	Data SDev	P01	P05	P10	P25	P50	P75	P90	P95	P99	Distribution	Pop-Estd Mean	Pop-Estd SDev
1-5	49	2.6	3.947			0.373	1	1.82	2.64	5.41	6.07		Gamma	2.25	1.89
6-11	68	2.52	3.496		0.171	0.373	0.619	1.11	2.91	6.98	11.7		Lognormal	2.78	5.12
12-19	50	1.33	1.457		0.123	0.258	0.404	0.609	2.27	3.41	4.78		Lognormal	1.54	2.44
Farmer	112	2.32	2.646	0.072	0.276	0.371	0.681	1.3	3.14	5	6.12	15.7	Lognormal	2.36	3.33

N = Number of samples; P01-P99 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.

G.2.4.3 **<u>Protected Fruit Consumption</u>.** Table G-6 presents protected fruit consumption data and distributions. Data for consumption of homegrown protected fruit were obtained from Table 13-62 of the EFH (U.S. EPA, 1997b). Data (in g WW/kg/d) were presented for those 12 to 19 years, 20 to 39 years, 40 to 69 years, and all ages. Available percentile data were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model.

Table G-6. Protected Fruit Consumption Data and Distributions

EFH Data (g WW/kg-d)													Distributors		
Age Cohort	N	Data Mean	Data SDev	P01	P05	P10	P25	P50	P75	P90	P95	P99	Distribution	Pop-Estd Mean	Pop-Estd SDev
1-5		ND	ND										Lognormal	6.5	15.9
6-11		ND	ND										Lognormal	6.5	15.9
12-19	20	2.96	4.441		0.16	0.283	0.393	1.23	2.84	7.44	11.4		Lognormal	2.91	6.39
20+	106	5.338	7.174		0.276	0.342	0.82	2.127	8.022	15.25	19.8		Lognormal	6.67	17.7
All ages	173	5.74	8.221	0.15	0.266	0.335	0.933	2.34	7.45	16	19.7	47.3	Lognormal	6.5	15.9
Farmer		ND	ND										Lognormal	6.67	17.7

N = Number of samples; P01-P99 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.

Data were not available for farmers or those ages 1 to 2, 3 to 5, and 6 to 11 years. "All ages" data were used for 1- to 5- and 6- to 11-year-olds because no age-specific data were available for those age groups. For the child1 and child2 age groups, the lognormal model is most appropriate because lognormal fits the best in other age groups for protected fruit and vegetables; the population estimated mean and standard deviation for all age groups were used for the analysis (normalized to body weight). For farmers, the population estimated mean and standard deviation for those older than 20 years (derived from the weighted average of means and standard deviations of those ages 20 to 39 years and those ages 40 to 69 years) were used for the analysis; lognormal also fits the percentile data best for those older than 20 years. The fraction of protected fruit intake that is home-produced is 0.03 for households that farm (Table 13-71, U.S. EPA, 1997b).

G.2.4.4 <u>Exposed Vegetable Consumption</u>. Table G-7 presents exposed vegetable consumption data and distribution. Data for consumption of homegrown exposed vegetables were obtained from Table 13-63 of the EFH (U.S. EPA, 1997b). Data (in g WW/kg/d) were presented for those ages 1 to 2, 3 to 5, 6 to 11, 12 to 19, 20 to 39, and 40 to 69 years, as well as farmers. Weighted averages of percentiles, means, and standard deviations were calculated for the 1- to 5-yr-old age group (combining groups of those ages 1 to 2 years and 3 to 5 years). Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model. The fraction of exposed vegetable intake that is home-produced is 0.42 for households that farm (Table 13-71, U.S. EPA, 1997b).

Table G-7. Exposed Vegetable Consumption Data and Distributions

EFH Data (g WW/kg-d)													Distributions		
Age Cohort	N	Data Mean	Data SDev	P01	P05	P10	P25	P50	P75	P90	P95	P99	Distribution	Pop-Estd Mean	Pop-Estd SDev
1-5	105	2.453	2.675		0.102	0.37	0.833	1.459	3.226	6.431	8.587		Gamma	2.55	2.58
6-11	134	1.39	2.037		0.044	0.094	0.312	0.643	1.6	3.22	5.47	13.3	Lognormal	1.64	3.95
12-19	143	1.07	1.128		0.029	0.142	0.304	0.656	1.46	2.35	3.78	5.67	Gamma	1.08	1.13
Farmer	207	2.17	2.316		0.184	0.372	0.647	1.38	2.81	6.01	6.83	10.3	Lognormal	2.38	3.5

N = Number of samples; P01-P99 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.

G.2.4.5 <u>Root Vegetable Consumption</u>. Table G-8 presents root vegetable consumption rate and distributions. Homegrown root vegetable consumption data were obtained from Table 13-65 of the EFH (U.S. EPA, 1997b). Data (in g WW/kg/d) were presented for those ages 1 to 2, 3 to 5, 6 to 11, 12 to 19, 20 to 39, 40 to 69 years, and adult farmers. Weighted averages of percentiles, means, and standard deviations were calculated for the child1 age group (combining groups of those ages 1 to 2 and 3 to 5 years). Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model. The fraction of root vegetable intake that is home-produced is 0.173 for households that farm (Table 13-71, U.S. EPA, 1997b).

Table G-8. Root Vegetable Consumption Data and Distributions

EFH Data (g WW/kg-d)													Distributions		
Age Cohort	N	Data Mean	Data SDev	P01	P05	P10	P25	P50	P75	P90	P95	P99	Distribution	Pop-Estd Mean	Pop-Estd SDev
1-5	45	1.886	2.371		0.081	0.167	0.291	0.686	2.653	5.722	7.502		Lognormal	2.31	6.05
6-11	67	1.32	1.752		0.014	0.036	0.232	0.523	1.63	3.83	5.59		Weibull	1.38	2.07
12-19	76	0.937	1.037		0.008	0.068	0.269	0.565	1.37	2.26	3.32		Weibull	0.99	1.19
Farmer	136	1.39	1.469	0.111	0.158	0.184	0.365	0.883	1.85	3.11	4.58	7.47	Lognormal	1.45	2.06

N = Number of samples; P01-P99 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.

G.2.4.6 Dairy Products (Milk) Consumption. Table G-9 presents milk consumption data and distribution. Data were obtained from Tables 13-28 and 11-2 of the EFH (U.S. EPA, 1997b). Data for consumption of home-produced dairy products (in g WW/kg/d) were presented only for those 20 to 39 years old and farmers (Table 13-28). No age-specific data for children were available for home-produced dairy products consumption. Per capita intake data for dairy products (including store-bought products), however, were available for those 1 to 2, 3 to 5, 6 to 11, and 12 to 19 years old (Table 11-2). Therefore, the per capita intake data were used for the children of farmers. Weighted averages of percentiles, means, and standard deviations were calculated for the 1- to 5-yr-old age group (combining those 1 to 2 years old and those 3 to 5 years old). Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select Weibull as the most appropriate model in all cases. The fraction of dairy product intake that is home-produced is 0.254 for households that farm (Table 13-71, U.S. EPA, 1997b).

Table G-9. Milk Consumption Data and Distributions

EFH Data (g WW/kg-d)											Distributions		
Age Cohort	N	Data Mean	Data SDev	P05	P10	P25	P50	P75	P90	P95	Distribution	Pop-Estd Mean	Pop-Estd SDev
1-5	2	23.71	35.86	2.98	7.47	13.56	21.5	32.22	42.63	49.62	Weibull	23.6	14.3
6-11	1	13.33	20	1.81	3.54	6.72	11.88	18.58	25.38	28.76	Weibull	13.3	8.7
12-19	1	6.293	9.44	0.27	0.61	2.31	5.29	9.2	12.75	15.12	Weibull	6.23	5.49
Farmer	63	17.1	15.8	0.736	3.18	9.06	12.1	20.4	34.9	44	Weibull	16.3	13.1

N = Number of samples; P05-P95 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.

G.2.4.7 Beef Consumption. Table G-10 presents beef consumption data and distributions. Home-produced beef consumption data were obtained from Table 13-36 of the EFH (U.S. EPA, 1997b). Data (in g WW/kg-d) were presented for farmers and those 6 to 11, 12 to 19, 20 to 39, and 40 to 69 years old. Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model.

Data were not available for those 1 to 2 and 3 to 5 years old. For beef consumption for those 1- to 5-yr-olds, the lognormal model was used because, among the other age groups, it was the best-fitted model in all but one case. The population-estimated mean and standard deviation for 6- to 11-yr-olds were used for 1- to 5-yr-olds for the analysis (normalized for body weight) and are supported by data in Table 11-3 (per capita intake for beef, including store-bought products), which indicate that those 1 to 2, 3 to 5, and 6 to 11 years old have the highest consumption rate of beef on a g/kg-d basis. The fraction of beef intake that is home-produced is 0.485 for households that farm (Table 13-71, U.S. EPA, 1997b).

Beef consumption rate data were adjusted to account for food preparation and cooking losses. A mean net cooking loss of 27 percent accounts for dripping and volatile losses during cooking (averaged over various cuts and preparation methods). A mean net post cooking loss of 24 percent accounts for losses from cutting, shrinkage, excess fat, bones, scraps, and juices. These data were obtained from Table 13-5 of the EFH (U.S. EPA, 1997b).

Table G-10. Beef Consumption Data and Distributions

EFH Data (g WW/kg-d)													Distributions		
Age Cohort	N	Data Mean	Data SDev	P01	P05	P10	P25	P50	P75	P90	P95	P99	Distribution	Pop-Estd Mean	Pop-Estd SDev
1-5		ND	ND										Lognormal	3.88	4.71
6-11	38	3.77	3.662		0.663	0.753	1.32	2.11	4.43	11.4	12.5		Lognormal	3.88	4.71
12-19	41	1.72	1.044		0.478	0.513	0.896	1.51	2.44	3.53	3.57		Gamma	1.77	1.12
Farmer	182	2.63	2.644	0.27	0.394	0.585	0.896	1.64	3.25	5.39	7.51	11.3	Lognormal	2.5	2.69

N = Number of samples; P01-P99 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.

G.2.4.8 Fish Consumption. Table G-11 presents fish consumption data and distributions. Fish consumption data were obtained from Table 10-64 of the EFH (U.S. EPA, 1997b). Data (in g/d) were available for adult freshwater anglers in Maine. The Maine fish consumption study was one of four recommended freshwater angler studies in the EFH (U.S. EPA, 1997b). The other recommended fish consumption studies (i.e., Michigan and New York) had large percentages of anglers who fished from Great Lakes, which is not consistent with the modeling scenarios used in this risk analysis. The anglers in the Maine study fished from streams, rivers, and ponds; these data are more consistent with our modeling scenarios. Although the Maine data have a lower mean than the Michigan data, the Maine data compared better with a national USDA study. Also, the Maine study had percentile data available, which were necessary to develop a distribution.

Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) and measures of goodness of fit were used to select lognormal as the most appropriate model. The fraction of fish intake that is locally caught is 0.325 for adult fishers (Table 13-71, U.S. EPA, 1997b). The fraction of consumed trophic level 3 (T3) and trophic level 4 (T4) fish was 0.36 and 0.64, respectively (Table 10-66, U.S. EPA, 1997b).

Table G-11. Fish Consumption Data and Distributions

EFH Data (g/d)									Distributions		
Age Cohort	N	Data Mean	Data SDev	P50	P66	P75	P90	P95	Distribution	Pop-Estd Mean	Pop-Estd SDev
All ages	1,053	6.4		2	4	5.8	13	26	Lognormal	6.48	19.9

N = Number of samples; P50-P95 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.

G.2.4.9 <u>Drinking Water Intake</u>. Table G-12 presents drinking water intake data and distributions. Drinking water intake data were obtained from Table 3-6 of the EFH (U.S. EPA, 1997a). Data (in mL/d) were presented by age groups. Weighted averages of percentiles, means, and standard deviations were calculated for the three child age groups and adults. Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model. The fraction of drinking water contaminated was assumed to be 1 (in accordance with EPA policy).

Table G-12. Drinking Water Intake Data and Distributions

EFH Data – (mL/d)													Distributions		
Age Cohort	N	Data Mean	Data SDev	P01	P05	P10	P25	P50	P75	P90	P95	P99	Distribution	Pop-Estd Mean	Pop-Estd SDev
1-5	3,200	697.1	401.5	51.62	187.6	273.5	419.2	616.5	900.8	1,236	1,473	1,917	Gamma	698	406
6-11	2,405	787	417	68	241	318	484	731	1,016	1,338	1,556	1,998	Gamma	787	430
12-19	5,801	963.2	560.6	65.15	241.4	353.8	574.4	868.5	1,247	1,694	2,033	2,693	Gamma	965	574
20+	13,394	1,384	721.6	207.6	457.5	607.3	899.6	1,275	1,741	2,260	2,682	3,737	Gamma	1,383	703

N = Number of samples; P01-P99 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.

G.2.4.10 <u>Inhalation Rate</u>. Table G-13 presents inhalation rate data and distribution. No percentile data were available for the inhalation rate, and the default lognormal model was assumed. In an analysis of inhalation data, Myers et al. (U.S. EPA, 2000) found that, for those younger than 3 years, CV was close to 70 percent; for other age groups, it was close to 30 percent. The lognormal distribution was fitted by using CV=50 percent [(30+70)/2] for the 1- to 5-yr-old age group and CV=30 percent for the 6- to 11-yr-olds, 12- to 19-yr-olds, and adult age groups.

Table G-13. Inhalation Rate Data and Distribution

Age Cohort	Distribution	Population-Estimated Mean (m^3/d)	Population-Estimated SDev (m^3/d)
1-5	Lognormal	7.55	3.78
6-11	Lognormal	11.75	3.53
12-19	Lognormal	14.0	4.2
Adult	Lognormal	13.3	3.99

SDev = Standard deviation.

G.2.4.11 <u>Shower Parameters</u>. Table G-14 presents shower parameters and distributions. Percentile data for time spent taking a shower were provided in Table 15-21 of the EFH (U.S. EPA, 1997c). Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model for each age variable.

Table G-14. Shower Parameters and Distributions

EFH Data (minutes)													Distributions		
Parameter	Age Cohort	N	P02	P05	P10	P25	P50	P75	P90	P95	P98	P99	Distribution	Pop-Estd Mean	Pop-Estd SDev
Shower time	All ages	3,547	4		5	10	15	20	30	35	50	60	Gamma	16.7	9.91

N = Number of samples; P02-P99 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.

G.2.4.12 <u>Body Weight</u>. Table G-15 presents body weight data and distribution. Body weight data were obtained from Tables 7-2 through 7-7 of the EFH (U.S. EPA, 1997a). Data (in kg) were presented by age and gender. Weighted averages of percentiles, means, and standard deviations were calculated for 1- to 5-yr-olds, 6- to 11-yr-olds, 12- to 19-year olds, and adult age groups; male and female data were weighted and combined for each age group. These percentile data were used as the basis for fitting distributions. These data were analyzed to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model.

Table G-15. Body Weight Data and Distributions

EFH Data – (kg)													Distributions		
Age Cohort	N	Data Mean	Data SDev	P05	P10	P15	P25	P50	P75	P85	P90	P95	Distribution	Pop-Estd Mean	Pop-Estd SDev
1-5	3,762	15.52	3.719	12.5	13.1	13.45	14.03	15.26	16.67	17.58	18.32	19.45	Lognormal	15.5	2.05
6-11	1,725	30.84	9.561	22.79	24.05	25.07	26.44	29.58	33.44	36.82	39.66	43.5	Lognormal	30.7	5.96
12-19	2,615	58.45	13.64	43.84	46.52	48.31	50.94	56.77	63.57	68.09	71.98	79.52	Lognormal	58.2	10.2
20+	12,504	71.41	15.45	52.86	55.98	58.21	61.69	69.26	78.49	84.92	89.75	97.64	Lognormal	71.2	13.3

N = Number of samples; P05-P95 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.

G.2.4.13 <u>Exposure Duration</u>. Table G-16 presents exposure duration data and distributions. Exposure duration was assumed to be equivalent to the average residence time for each receptor. Exposure durations for adult and child residents were determined using data on residential occupancy from the EFH, Table 15-168 (U.S. EPA, 1997c). The data represent the total time a person is expected to live at a single location, based on age. The table presented male and female data combined. For adult residents, age groups from 21 to 90 were pooled. For child residents, the 3-yr-old age group was used for the 1- to 5-yr-olds. The 6- and 9-yr-old age groups were pooled for the 6- to 11-yr-old cohort.

Table G-16. Exposure Duration Data and Distributions

EFH Data		Distributions		
Age Cohort	Data Mean (yr)	Distribution	Pop-Estd Shape (yr)[a]	Pop-Estd Scale (yr)
1-5	6.5	Weibull	1.32	7.059
6-11	8.5	Weibull	1.69	9.467
Adult	16.0	Weibull	1.34	17.38
Farmer	18.75	Gamma	0.607	29.76

Pop-Estd = Population-estimated.
SDev = Standard deviation.
[a] Distributions used in risk assessment.

In an analysis of residential occupancy data, Myers et al. (U.S. EPA, 2000) found that the data, for most ages, were best fit by a Weibull distribution. The Weibull distribution as implemented in Crystal Ball® is characterized by three parameters: location, shape, and scale. Location is the minimum value and, in this case, was presumed to be 0. Shape and scale were determined by fitting a Weibull distribution to the pooled data, as follows. To pool residential occupancy data for the age cohorts, an arithmetic mean of data means was calculated for each age group. Then, assuming a Weibull distribution, the variance within each age group (e.g., 6-yr-olds) was calculated in the age cohort. These variances in turn were pooled over the age cohort using equal weights. This is not the usual type of pooled variance, which would exclude the variation in the group means. However, this way the overall variance reflected the variance of means within the age groups (e.g., within the 6-yr-old age group). The standard deviation was estimated as the square root of the variance. The coefficient of variation was calculated as the ratio of the standard deviation divided by the Weibull mean. For each cohort, the population-estimated parameter uncertainty information (e.g., shape and scale) was calculated based on a Weibull distribution, the calculated data mean for the age cohort, and the CV.

Exposure durations for adult and child farmers were determined using data on residential occupancy from the EFH, Tables 15-163 and 15-164 (U.S. EPA, 1997c). The data represent the total time a person is expected to live at a single location, based on household type. Age-specific data were not provided. For residence duration of farmers (U.S. EPA 1997c, Tables 15-163 and 15-164), the gamma model was used because it was the best fitted model in five age groups and was the second best fitted model in two cases (based on data in U.S. EPA 1997c, Tables 15-167 and 15-168). A population mean of 18.07 years and a population standard deviation of 23.19 years were calculated for farmers (all ages).

G.2.5 Minimums/Maximums

Probabilistic risk analyses involve “sampling” values from PDFs and using the values to estimate risk. In some cases, distributions are infinite, and there is a probability, although very small, that very large or very small values might be selected from the distributions. Because selecting extremely large or extremely small values is unrealistic (e.g., the range of adult body weights is not infinite), maximum and minimum values were imposed on the distributions. The minimum and maximum values are summarized in Table G-17. For the probabilistic analyses, the maximum intake rates for most food items were defined as 2 × (mean + 3 SD). For adult farmer beef, adult farmer exposed fruit, and child3 exposed vegetable, 2 × 99th percentile value was used as the maximum intake rates. For fish, subsistence fisher ingestion rates were used as the maximum. For soil, the 75th percentile for pica child was used as the maximum. Minimum intake values for all food items were zero.

Table G-17. Minimum and Maximum Values

Receptor	Parameter Name	Minimum	Source	Maximum	Source
General	Averaging time for carcinogens				
Adult resident	Body weight (adult)	15	0.5*(mean-3SD)	300	Prof. judgment
Child resident	Body weight (child 1)	4	0.5*(mean-3SD)	50	Prof. judgment
Child resident	Body weight (child 2)	6	0.5*(mean-3SD)	200	Prof. judgment
Child resident	Body weight (child 3)	13	0.5*(mean-3SD)	300	Prof. judgment
Farmer	Consumption rate: beef (adult farmer)	0		23	2*(P99)
Child farmer	Consumption rate: beef (child 1 farmer)	0		36	2*(mean+3SD)
Child farmer	Consumption rate: beef (child 2 farmer)	0		36	2*(mean+3SD)
Child farmer	Consumption rate: beef (child 3 farmer)	0		10	2*(mean+3SD)
Child farmer	Consumption rate: exposed fruit (child 1 farmer)	0		16	2*(mean+3SD)
Child farmer	Consumption rate: exposed fruit (child 2 farmer)	0		36	2*(mean+3SD)
Child farmer	Consumption rate: exposed fruit (child 3 farmer)	0		18	2*(mean+3SD)
Farmer	Consumption rate: exposed fruit (farmer)	0		31	2*(P99)
Farmer	Consumption rate: exposed vegetables (adult farmer)	0		26	2*(mean+3SD)
Child farmer	Consumption rate: exposed vegetables (child 1 farmer)	0		21	2*(mean+3SD)
Child farmer	Consumption rate: exposed vegetables (child 2 farmer)	0		27	2*(mean+3SD)
Child farmer	Consumption rate: exposed vegetables (child 3 farmer)	0		11	2*(P99)
Fisher	Consumption rate: fish (adult fisher)	0		1500	EFH-subsist
Farmer	Consumption rate: milk (adult farmer)	0		111	2*(mean+3SD)
Child farmer	Consumption rate: milk (child 1 farmer)	0		133	2*(mean+3SD)
Child farmer	Consumption rate: milk (child 2 farmer)	0		79	2*(mean+3SD)
Child farmer	Consumption rate: milk (child 3 farmer)	0		45	2*(mean+3SD)
Child farmer	Consumption rate: protected fruit (child 1 farmer)	0		108	2*(mean+3SD)
Child farmer	Consumption rate: protected fruit (child 2 farmer)	0		108	2*(mean+3SD)

(continued)

Table G-17. (continued)

Receptor	Parameter Name	Minimum	Source	Maximum	Source
Child farmer	Consumption rate: protected fruit (child 3 farmer)	0		44	2*(mean+3SD)
Farmer	Consumption rate: protected fruit (farmer)	0		120	2*(mean+3SD)
Child farmer	Consumption rate: root vegetables (child 1 farmer)	0		41	2*(mean+3SD)
Child farmer	Consumption rate: root vegetables (child 2 farmer)	0		15	2*(mean+3SD)
Child farmer	Consumption rate: root vegetables (child 3 farmer)	0		9	2*(mean+3SD)
Farmer	Consumption rate: root vegetables (farmer)	0		15	2*(mean+3SD)
Adult resident	Event frequency (shower)				
Adult resident	Exposure duration (adult resident)	1		50	
Child resident	Exposure duration (child)	1		50	
Farmer	Exposure duration (farmer)	1		50	
Adult resident	Ingestion rate: drinking water (adult resident)	104	0.5*(P01)	11000	EFH-active, hot
Child farmer	Ingestion rate: drinking water (child 1 resident)	26	0.5*(P01)	3840	2*(P99)
Child farmer	Ingestion rate: drinking water (child 2 resident)	34	0.5*(P01)	4200	2*(mean+3SD)
Child farmer	Ingestion rate: drinking water (child 3 resident)	33	0.5*(P01)	5400	2*(P99)
Child farmer	Ingestion rate: soil (child 1 resident)	5E-07	Prof. judgment	0.03	EFH-P75 pica
Adult resident	Inhalation (breathing) rate (adult resident)	1	0.5*(mean-3SD)	50	2*(mean+3SD)
Child resident	Inhalation (breathing) rate (child 1 resident)	1	0.5*(mean-3SD)	40	2*(mean+3SD)
Child resident	Inhalation (breathing) rate (child 2 resident)	1	0.5*(mean-3SD)	45	2*(mean+3SD)
Child resident	Inhalation (breathing) rate (child 3 resident)	1	0.5*(mean-3SD)	55	2*(mean+3SD)
Adult resident	Shower time	1	Prof. judgment	60	Prof. Judgment

Table G-18. Exposure Factor Raw Data: Descriptive Statistics by Standardized Age Groups

Parameter	Age Cohort	N	Avg	SDev	Units	P01	P02	P05	P10	P15	P25	P50	P75	P85	P90	P95	P98	P99
beef	6-11	38	3.77	3.662	g WW/kg-d			0.663	0.753		1.32	2.11	4.43		11.4	12.5		
beef	12-19	41	1.72	1.044	g WW/kg-d			0.478	0.513		0.896	1.51	2.44		3.53	3.57		
beef	Farmer	182	2.63	2.644	g WW/kg-d	0.27		0.394	0.585		0.896	1.64	3.25		5.39	7.51		11.3
bodywt	1-5	3,762	15.52	3.719	kg			12.5	13.1	13.45	14.03	15.26	16.67	17.58	18.32	19.45		
bodywt	6-11	1,725	30.84	9.561	kg			22.79	24.05	25.07	26.44	29.58	33.44	36.82	39.66	43.5		
bodywt	12-19	2,615	58.45	13.64	kg			43.84	46.52	48.31	50.94	56.77	63.57	68.09	71.98	79.52		
bodywt	20+	12,504	71.41	15.45	kg			52.86	55.98	58.21	61.69	69.26	78.49	84.92	89.75	97.64		
cumTroom	All ages	6,661	35.02	48.8	min			5			15	25	40		60	90	137	255
drinkH_2O	1-5	3,200	697.1	401.5	mL/d	51.62		187.6	273.5		419.2	616.5	900.8		1236	1473		1917
drinkH_2O	6-11	2,405	787	417	mL/d	68		241	318		484	731	1016		1338	1556		1998
drinkH_2O	12-19	5,801	963.2	560.6	mL/d	65.15		241.4	353.8		574.4	868.5	1247		1694	2033		2693
drinkH_2O	20+	13,394	1384	721.6	mL/d	207.6		457.5	607.3		899.6	1275	1741		2260	2682		3737
expfruit	1-5	49	2.6	3.947	g WW/kg-d				0.373		1	1.82	2.64		5.41	6.07		
expfruit	6-11	68	2.52	3.496	g WW/kg-d			0.171	0.373		0.619	1.11	2.91		6.98	11.7		
expfruit	12-19	50	1.33	1.457	g WW/kg-d			0.123	0.258		0.404	0.609	2.27		3.41	4.78		
expfruit	Farmer	112	2.32	2.646	g WW/kg-d	0.072		0.276	0.371		0.681	1.3	3.14		5	6.12		15.7
expveg	1-5	105	2.453	2.675	g WW/kg-d			0.102	0.37		0.833	1.459	3.226		6.431	8.587		
expveg	6-11	134	1.39	2.037	g WW/kg-d			0.044	0.094		0.312	0.643	1.6		3.22	5.47		13.3
expveg	12-19	143	1.07	1.128	g WW/kg-d			0.029	0.142		0.304	0.656	1.46		2.35	3.78		5.67
expveg	Farmer	207	2.17	2.316	g WW/kg-d			0.184	0.372		0.647	1.38	2.81		6.01	6.83		10.3
milk	1-5	40	23.71	3.838	g WW/kg-d			2.98	7.47		13.56	21.5	32.22		42.63	49.62		

(continued)

Table G-18. (continued)

Parameter	Age Cohort	N	Avg	SDev	Units	P01	P02	P05	P10	P15	P25	P50	P75	P85	P90	P95	P98	P99
milk	6-11	20	13.33	1.181	g WW/kg-d			1.81	3.54		6.72	11.88	18.58		25.38	28.76		
milk	12-19	20	6.293	0.657	g WW/kg-d			0.27	0.61		2.31	5.29	9.2		12.75	15.12		
milk	Farmer	63	17.1	15.8	g WW/kg-d			0.736	3.18		9.06	12.1	20.4		34.9	44		
profruit	12-19	20	2.96	4.441	g WW/kg-d			0.16	0.283		0.393	1.23	2.84		7.44	11.4		
profruit	20+	106	5.338	7.174	g WW/kg-d			0.276	0.342		0.82	2.127	8.022		15.25	19.8		
profruit	All ages	173	5.74	8.221	g WW/kg-d	0.15		0.266	0.335		0.933	2.34	7.45		16	19.7		47.3
rootveg	1-5	45	1.886	2.371	g WW/kg-d			0.081	0.167		0.291	0.686	2.653		5.722	7.502		
rootveg	6-11	67	1.32	1.752	g WW/kg-d			0.014	0.036		0.232	0.523	1.63		3.83	5.59		
rootveg	12-19	76	0.937	1.037	g WW/kg-d			0.008	0.068		0.269	0.565	1.37		2.26	3.32		
rootveg	Farmer	136	1.39	1.469	g WW/kg-d	0.111		0.158	0.184		0.365	0.883	1.85		3.11	4.58		7.47
showerT	All ages	3,547			min	3	4		5		10	15	20		30	35	50	60

Avg = average; N = number of samples; P01-P99 = percentiles; SDev = standard deviation.
Source: *Exposure Factors Handbook* (U.S. EPA, 1997a, 1997b, 1997c).

Table G-19. Population-Estimated Averages, Standard Deviations, and Coefficients of Variation

Parameter	Age Cohort	N	First	Data Mean	GAM Mean	LOG Mean	WEI Mean	Data SDev	GAM SDev	LOG SDev	WEI CV	Data CV	GAM CV	LOG CV	WEI CV
beef	6-11	38	Lognormal	3.77	3.83	3.88	3.86	3.66	3.48	4.71	3.67	0.97	0.91	1.22	0.95
beef	12-19	41	Gamma	1.72	1.77	1.82	1.76	1.04	1.12	1.41	1.07	0.61	0.64	0.78	0.61
beef	Farmer	182	Lognormal	2.63	2.47	2.5	2.49	2.64	2.02	2.69	2.09	1.01	0.82	1.07	0.84
bodywt	1-5	3,762	Lognormal	15.5	15.5	15.5	15.4	3.72	2.05	2.05	2.35	0.24	0.13	0.13	0.15
bodywt	6-11	1,725	Lognormal	30.8	30.7	30.7	30.4	9.56	5.94	5.96	6.87	0.31	0.19	0.19	0.23
bodywt	12-19	2,615	Lognormal	58.5	58.1	58.2	57.7	13.6	10.2	10.2	11.6	0.23	0.17	0.18	0.2
bodywt	20+	12,504	Lognormal	71.4	71.2	71.2	70.7	15.5	13.2	13.3	14.8	0.22	0.18	0.19	0.21
cumTroom	All ages	6,661	Lognormal	35	33.6	34	33.8	48.8	27.3	34.6	29.2	1.39	0.81	1.02	0.86
drinkH_2O	1-5	3,200	Gamma	697	698	719	698	401	406	510	390	0.58	0.58	0.71	0.56
drinkH_2O	6-11	2,405	Gamma	787	787	808	787	417	430	530	408	0.53	0.55	0.66	0.52
drinkH_2O	12-19	5,801	Gamma	963	965	1,000	964	561	574	739	546	0.58	0.6	0.74	0.57
drinkH_2O	20+	13,394	Gamma	1,384	1,383	1,405	1,382	722	703	821	688	0.52	0.51	0.58	0.5
expfruit	1-5	49	Gamma	2.6	2.25	2.46	2.25	3.95	1.89	2.91	1.84	1.52	0.84	1.18	0.82
expfruit	6-11	68	Lognormal	2.52	2.63	2.78	2.63	3.5	2.9	5.12	3.16	1.39	1.1	1.84	1.2
expfruit	12-19	50	Lognormal	1.33	1.43	1.54	1.44	1.46	1.44	2.44	1.51	1.1	1.01	1.59	1.05
expfruit	Farmer	112	Lognormal	2.32	2.24	2.36	2.24	2.65	2.1	3.33	2.18	1.14	0.94	1.41	0.97
expveg	1-5	105	Gamma	2.45	2.55	3.06	2.56	2.68	2.58	5.61	2.65	1.09	1.01	1.83	1.04

(continued)

Table G- 19. (continued)

Parameter	Age Cohort	N	First	Data Mean	GAM Mean	LOG Mean	WEI Mean	Data SDev	GAM SDev	LOG SDev	WEI CV	Data CV	GAM CV	LOG CV	WEI CV
expveg	6-11	134	Lognormal	1.39	1.4	1.64	1.39	2.04	1.66	3.95	1.81	1.47	1.19	2.41	1.3
Expveg	12-19	143	Gamma	1.07	1.08	1.32	1.08	1.13	1.13	2.69	1.15	1.05	1.05	2.03	1.07
Expveg	Farmer	207	Lognormal	2.17	2.22	2.38	2.22	2.32	2.13	3.5	2.18	1.07	0.96	1.47	0.98
Fish	All ages	1,053	Lognormal	6.4	5.24	6.48	5.45		8.3	19.9	9.79		1.58	3.07	1.8
Milk	1-5	40	Weibull	23.7	23.9	25.8	23.6	3.84	16	23.4	14.3	0.16	0.67	0.91	0.61
Milk	6B-11	20	Weibull	13.3	13.4	14.5	13.3	1.18	9.51	14	8.7	0.09	0.71	0.97	0.65
Milk	12-19	20	Weibull	6.29	6.28	8.17	6.23	0.66	5.9	14.9	5.49	0.1	0.94	1.83	0.88
Milk	Farmer	63	Weibull	17.1	16.4	19.8	16.3	15.8	13.9	28.3	13.1	0.92	0.85	1.43	0.8
Profruit	12-19	20	Lognormal	2.96	2.62	2.91	2.62	4.44	3.05	6.39	3.36	1.5	1.17	2.19	1.28
Profruit	20+	106	Lognormal	5.34	5.46	6.67	5.49	7.17	6.59	17.7	7.28	1.34	1.21	2.65	1.33
Profruit	All ages	173	Lognormal	5.74	5.76	6.5	5.7	8.22	6.83	15.9	7.46	1.43	1.19	2.44	1.31
Rootveg	1-5	45	Lognormal	1.89	1.95	2.31	1.95	2.37	2.37	6.05	2.63	1.26	1.22	2.62	1.35
Rootveg	6-11	67	Weibull	1.32	1.35	2.3	1.38	1.75	1.78	10.6	2.07	1.33	1.32	4.62	1.5
Rootveg	12-19	76	Weibull	0.94		1.7	0.99	1.04		5.97	1.19	1.11		3.51	1.2
Rootveg	Farmer	136	Lognormal	1.39	1.39	1.45	1.39	1.47	1.31	2.06	1.36	1.06	0.95	1.42	0.98
ShowerT	All ages	3,547	Gamma		16.7	16.9	16.8		9.91	11.8	10.1		0.59	0.7	0.6

CV = Coefficient of variation; CV = SDev/avg. GAM = Gamma; LOG = Lognormal; N = Number of samples; SDev = Standard deviation; WEI = Weibull.

G.3 References

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Appendix H

Distribution Coefficients

Appendix H

Distribution Coefficients

The development and use of partition coefficients is common to two ongoing U.S. Environmental Protection Agency (EPA) studies: paints manufacturing waste listing determination and inorganics chemical manufacturing waste listing determination. Accordingly, the work documented in this appendix covers metals that are common to both studies. Not all of these metals were evaluated in the risk assessment for the paints manufacturing waste listing determination.

Metal speciation and partitioning is an important factor in assessing the fate and mobility of metals in the environment. Because metals' behavior is affected by such a large number of simultaneously occurring processes, predicting metal speciation and partitioning is complex. Yet, the ability to understand and ultimately predict the fate and mobility of metals is fundamental to any risk assessment involving the release of metals to the environment. One approach to the problem has been to use distribution coefficient (K_d) values to describe metal partitioning between environmental substrates and aqueous phases. Within the context of this risk assessment, K_d values are required as constituent-specific inputs for EPA's Composite Model with Transformation Products (EPACMTP) vadose zone and aquifer modules. They are also required as constituent-specific inputs for source partition models and for aboveground fate and transport modeling of constituent concentrations in soils, watersheds, and waterbodies.

The K_d is metal-specific as well as system-specific. Depending on the metal and the system parameters, the K_d can vary over as many as six or seven orders of magnitude. Ranges of this size present a challenge in the estimation of a single generic K_d value for use in risk assessment models. Methods that have been used to estimate K_d values for risk assessment include

- The use of aqueous speciation models such as MINTEQA2, which predict metal partitioning between a specified substrate and aqueous phase based on the thermodynamics of the defined system

- Review and compilation of measured data reported in the scientific literature.

In response to concerns raised about the adequacy of the MINTEQA2 aqueous speciation model to estimate K_d values for use in risk assessment studies, EPA opted to use K_d

measurements compiled from the scientific literature for this risk assessment. For this work, EPA expanded on previous efforts that used empirical K_d values, including *Partitioning Coefficients for Metals in Surface Water, Soil, and Waste for HWIR99* (U.S. EPA, 1999a) and *Understanding Variation in Partition Coefficient, K_d, Values* (U.S. EPA, 1999b).

H.1 Literature Review

A literature review was undertaken to compile experimentally derived K_d values for soil and aquifer materials. The metals of interest included: antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), boron (B), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), manganese (Mn), molybdenum (Mo), mercury (Hg), nickel (Ni), selenium (Se), silver (Ag), thallium (Tl), tin (Sn), vanadium (V), and zinc (Zn). Cyanide (CN) was also likely to be of interest and was included in the literature search.

The general approach was to review and expand, as appropriate, upon two recent EPA efforts to identify and compile measured K_d values from literature sources. Specifically, these were the K_d data collection effort for the Hazardous Waste Identification Rule (HWIR; U.S. EPA, 1999a) and work conducted by EPA's Office of Air and Radiation (OAR) and the U.S. Department of Energy (DOE) (U.S. EPA, 1999b). The approach was designed to ensure that all relevant data were compiled and that the compiled data accurately reflect that reported in the scientific literature. Specific steps conducted as part of this literature review are described in the following subsections.

H.1.1 Step 1. Review and Comparison of Recent K_d Surveys

The HWIR and OAR databases were reviewed to determine which of the metals of interest to this study were represented in the two databases. The HWIR database contained a greater subset of target metals and became the foundation for this current effort. The OAR database was used to provide supplementary data for three metals common to both datasets (i.e., cadmium, chromium, and lead).

Distribution coefficient values representing soil/soil-water systems collected as part of the HWIR effort were compared to K_d values collected by the EPA/OAR study. The purpose of the comparison was to check for reasonable agreement in the values common to both studies and to identify gaps in the datasets. The comparison was limited to metals common to both studies and included cadmium, chromium, and lead. As shown in Figures H-1 through H-3, the median and lower limits of the two studies were similar. Differences in the two datasets were chiefly attributed to differences in the literature reviewed. The HWIR survey relied on information reported in the open literature whereas the OAR study included values from the open literature as well as from institutional reports such as those published by the Electric Power Research Institute and DOE. Where the studies used common references, the compiled data agreed well between the two reports.

On the basis of this comparison, it was concluded that, for the metals addressed, the HWIR and OAR surveys provide a solid data foundation for soil systems. However, because the HWIR survey did not address groundwater systems, K_d values for aquifer systems were lacking.

Furthermore, the HWIR survey did not include aquifer or soil system data for three constituents of concern (boron, manganese, and hydrogen cyanide). Hence, a supplemental literature search was designed and implemented to fill in these data gaps (see Step 3).

H.1.2 Step 2. Database Design

A simple database was designed and constructed to compile all K_d values collected under this effort as well as those collected as part of the HWIR and OAR surveys. Data collected as part of the HWIR survey were transferred electronically into the database. Random checks of the data were performed to confirm that the transfer was successful. Data from the OAR survey were keyed in and a 100 percent check of the keyed data was performed to ensure that all values were entered accurately.

The data dictionary is presented in Figure H-4. As shown, the database was designed to allow collection of all pertinent geochemical parameters reported in the references reviewed.

H.1.3 Step 3. Literature Survey

A literature survey was designed to identify measured K_d values that have been reported in the scientific literature. This survey was adopted from the HWIR survey plan and included the collection of published K_d values for the metals of interest in the environmental media of interest, estimation of K_d values from reported metal concentration data when feasible, and review of established relationships between K_d values and other variables, (U.S. EPA, 1999b, citing, for example, Strenge and Peterson, 1989, and Whelan et al., 1992). Relevant geochemical parameters (e.g., pH, metal concentration, sorbent content) were collected along with the K_d values when available. To the extent possible, the notation and procedure for collecting and calculating K_d values followed that in Lyon et al. (U.S. EPA, 1999b, citing Lyon et al., 1997).

Data sources included the scientific literature, EPA reports, and reports from other government and university sources. Electronic searches were conducted using the following databases:

- AGRICOLA (1970 - present)
- Analytical Abstracts (1980 - present)
- Applied Science and Technology Abstracts
- Aquatic Sciences and Fisheries Abstract Set (1981 - present)
- CAB Abstracts (1987 - present)
- Current Contents (1992 - present)
- Dissertation Abstracts (1981 - present)
- EI Compendex (1970 - present)
- Enviroline (1975 - present)
- Environmental Bibliography (1973 - present)
- GEOBASE (1980 - present)
- GEOREF (1985 - present)
- National Technical Information Service
- Pollution Abstracts (1970 - present)

- TOXLINE (1982 - present)
- WATERNET (1971 - present)
- Water Resources Abstracts (1987 - present).

Two separate searches were conducted. The first search focused on groundwater systems and included the entire suite of constituents of concern. Specifically, the literature was searched electronically for K_d values measured in groundwater systems for antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, lead, manganese, molybdenum, mercury, nickel, selenium, silver, thallium, tin, vanadium, zinc, hydrogen cyanide, and methylated mercury. The search string read as follows:

> *"partition coefficient" or "distribution coefficient" or "retardation factor" or "Kd" or "Kp" or "R" or "Rf" or "sorption" and "metal" and "ground water" or "ground water" or "aquifer" or "saturated zone"*

For each of these metals, the chemical name as well as the chemical symbol was included in the search string. For metals that are characterized by multiple oxidation states (e.g., arsenic and chromium), the important oxidation states were also added to the search string.

The second search focused on the three constituents not previously considered in the HWIR survey (i.e., boron, manganese, and hydrogen cyanide). The literature was searched electronically for K_d values measured in soil systems for boron, manganese, and hydrogen cyanide. The second search string read as follows:

> *"partition coefficient" or "distribution coefficient" or "Kd" or "Kp" or "sorption" and "constituent" and "soil" or "vadose zone" or "unsaturated zone"*

These strings were specifically designed to generate many citations, thereby decreasing the probability that relevant articles would be missed. However, the generality of the search strings also guaranteed that a significant number of the articles identified in the search would not contain relevant information. Because resources and schedule constraints prevented review of every single article in detail, a strategy was developed to expedite the review process.

Each of the titles returned in the literature search was reviewed for key words suggesting that the article might contain measured K_d values for one or more of the constituents of concern. For those titles that held promise, an electronic copy of the abstract was obtained and reviewed. Because it was frequently difficult to ascertain the contents of an article based solely on the title, all likely candidate abstracts were ordered. Each of the abstracts was then reviewed for information pertaining to the type and purpose of the study. The complete article was ordered if it seemed a likely candidate to contain experimentally measured K_d values for either groundwater or soil systems for the constituents of concern. Articles were reviewed and K_d values entered into the database.

The geochemical and measurement parameters most likely to influence the K_d were also entered into the database if specified in the article or report. Examples of these included media type, extractant, pH, total metal concentrations, dissolved organic carbon content, weight fraction of particulate organic matter, clay content, cation exchange capacity, and test method.

H.1.4 Step 4. Quality Assurance/Quality Control

Quality control activities included the following:

- Definition and documentation of criteria to judge the quality of the data and their relevance for use in modeling
- Comparison of data sources included in the HWIR and OAR datasets to ensure comprehensiveness and appropriateness of literature search criteria
- One hundred percent checks of all hand-entered data against the original sources
- Manual or parallel spreadsheet calculation checks of all automated data processing (e.g., data conversions, statistical analyses).

Quality control activities were performed by senior scientists with extensive experience in the field of geochemistry and in evaluation of K_d data in particular. Each of the articles was reviewed by two individuals, and the extracted data were cross checked.

H.2 Criteria For Selection of K_d Values

A set of criteria were defined for selection of K_d values from the literature. The criteria included:

- Natural soil or aquifer media as opposed to pure mineral phases or treated soils
- Aqueous solutions (extractants) with low ionic strength ($\leq$ 0.1 M), low humic material concentrations (< 5 mg/L), and dilute metal concentrations
- Absence of organic chelates (e.g., EDTA)
- pH values in the range of 4 to 10.

Batch leach tests were considered to represent systems closer to equilibrium and were preferred over column tests (when both were available for the same study and soil). Langmuir isotherm data were not used. Freundlich isotherm data were used and converted to K_d by assuming 1 part per million. For some field studies, measured retardation factors (Rf) were also used to calculate K_d. In these cases, the following equation was used:

$$(Rf - 1)/(\text{bulk density}/\text{effective porosity}) = K_d.$$

If multiple K_d values were reported for the same soil type within a single reference, only one K_d was selected to avoid biasing the data in favor of any one researcher. The value selected was that most closely approximating natural conditions (i.e., unadjusted values on untreated samples using natural extractants).

H.4 Results of the Literature Search

A total of 57 articles were obtained and reviewed. Distribution coefficient values were compiled and entered into the database along with those values collected during the HWIR and EPA/OAR studies (U.S. EPA, 1999a and 1999b, respectively). The HWIR effort was broader in its scope and resulted in review of approximately 245 articles and reports pertaining to metal partitioning between soil and soil-water, between suspended matter and surface water, between sediment and sediment-pore water, and between dissolved organic carbon and the dissolved inorganic phase in natural waters. Although all the HWIR data were imported into the database, only those data specific to soil and groundwater systems were used in this risk assessment.

Table H-1 presents summary statistics for the dataset. As expected, references were not obtained for the full suite of constituents of concern. There was a preponderance of data for arsenic, boron, cadmium, cobalt, copper, lead, nickel, and zinc. Although one of the objectives of the literature search was to determine separate K_d values for all metals that occur in multiple environmentally relevant oxidation states, this proved possible only for chromium. Other metals such as arsenic, selenium, and antimony are known to occur in multiple oxidation states, but the retrieved data were not adequate to clearly differentiate K_d values among different oxidation states for these metals. Hence, results are presented for arsenic, selenium, and antimony without specifying oxidation state. Chromium is the exception and results are reported for Cr(III) and Cr(VI).

Molybdenum and vanadium are known to exhibit multiple oxidation states as well. For these metals, it was assumed that the K_d values reported in the literature correspond to those expected for molybdate and vanadate, respectively.

H.5 Analysis of Retrieved Data and Development of K_d Ranges

Once the literature search and data compilation were complete it was necessary to prepare K_d values for use as input parameters for the source model and the soil and groundwater fate and transport models. Because K_d varies by several orders of magnitude for most metals, and because these models are known to be sensitive to K_d (in the context of calculating a retardation coefficient, R), it is appropriate to represent K_d as a distributed variable in the Monte Carlo runs. Two approaches were used to generate these distributions, depending on the availability of data: (1) a rank-order percentile approach was used to formulate empirical probability distributions from available measurements for metals with six or more literature K_d values, or (2) a log uniform distribution was used to represent variability when empirical K_d data were limited to five or fewer samples.

Empirical distributions were used because, although the literature review captured most, if not all, available measured K_d values, the data were judged to be inadequate to definitively fit a distribution type. Specifically, the sample represented by a collection of literature-derived data is not a random sample of all possible K_d values. Potential bias is introduced when selecting soil or groundwater systems for a study, and distribution fitting and parameterizing generally require a random sample. In addition, the number of values compiled for many metals was not adequate to apply routines to determine distribution type. In summary, the empirical distribution approach offers the following advantages to assuming a distribution type like lognormal, gamma, or Weibull:

- It honors the measured values collected for the study.
- It is simple to apply and explain.
- It captures the measured range and variability of K_d values in soil and groundwater.

The development of these empirical distributions is described in Section H.5.1. For metals for which the number of variables was not adequate to represent the data empirically, a loguniform distribution was assumed as described in Section H.5.2. Section H.5.3 describes the raw database of K_d values collected from the literature.

H.5.1 Empirical Distributions

An empirical distribution was developed for each metal represented by six or more literature K_d values (As, B, Cd, Cr(III), Cr(VI), Co, Cu, Pb, Mn, Hg, Ni, Se, Ag, and Zn). For each of these metals, the literature K_d values were listed in ascending order and ranked from 1 to N (N being the number of literature values). The cumulative distribution function (CDF) value for each K_d value was then calculated using the following formula:

CDF = rank/(1 + N); where N is the total number of literature K_d values.

To account for uncertainty regarding whether the highest and lowest values in a dataset are the true maximum and minimum, the measured value range was extended as follows. The interval between the first two literature values was subtracted from the first to get a K_d value for CDF = 0. If this resulted in a negative value, then the CDF = 0 value was half of the first K_d value. The interval between the last two literature values was then added to the last to get a K_d value for CDF = 1.

Tables H-2 through H-15 show the empirical CDF distributions developed from the collected literature K_d values for each of these metals.

H.5.2 Loguniform Distributions

For all of the metals with five or fewer literature K_d values (Ba, Be, Tl, Mo, Sb, Sn, and V), a loguniform distribution was assumed. The loguniform shape was selected because, in general, K_d distributions are skewed with a long right tail, but distribution type cannot be definitively determined. The range of this distribution (3 log units or 3 orders of magnitude) was based on the observation that, for the empirical distributions, the average range of measured values was about 3 log units.

To develop the loguniform distribution for a metal, the logarithms of the literature K_d values were averaged. Using the average logarithm value, a value of 1.5 was added to get a maximum value for the distribution, and 1.5 was subtracted to get a minimum value. The inverse logarithms of the minimum and the maximum were then taken to get the final minimum and maximum K_d values for the loguniform distribution.

This approach could not be applied in the case of Tl. There were no measured K_d values found for Tl in the open scientific literature. Loux et al. (1990) presented K_d values determined from aquifer material/groundwater samples obtained from six states (Wisconsin, Oregon, Florida, Texas, Utah, and New Jersey). The samples were subjected to acid-base additions so that K_d values were obtained at various pH values ranging from 2 to 11. The range in log K_d measured in these samples was from 0 to about 3 L/kg. Because this was the only instance of measured K_d values found for Tl, the range observed by Loux et al. (1990) was used to define a loguniform distribution—the log K_d was assumed to vary from 0 to 3 L/kg. This approach is consistent with the methodology used to treat the other metals for which there was a paucity of data.

Table H-16 lists the parameters of the loguniform distributions for metals with few (five or less) measured values. No values are presented for CN because no measured K_d values were found in the scientific literature. In a recent review of the behavior of CN in soil and groundwater, Kjeldsen (1999) suggests that retardation of CN transport due to sorption is expected to be of minor importance in most soils. To ensure conservatism, the K_d for CN was set equal to zero.

H.5.3 The Database of Literature K_d Values

The K_d values collected from the literature and used to create the distributions are listed in Tables H-17 and H-18. Each table provides, by metal, the K_d and log K_d values and corresponding reference information (reference index). The reference index consists of the first two or three letters of the first author's surname and the year of publication. Each reference index corresponds with a fully cited reference listed in Section H.8; the reference index is listed at the end of each citation. The "Study" heading in the tables indicates the EPA study that collected each value, with "Listing" indicating this study, "HWIR" indicating values collected by the Office of Solid Waste (OSW) for the Hazardous Waste Identification Rule risk modeling effort (U.S. EPA, 1999a), and "OAR" indicating values recently collected by EPA's Office of Air and Radiation (U.S. EPA, 1999b). Note that HWIR and OAR values were collected directly from those study reports and are, therefore, secondary values and citations.

Table H-17 also includes a description of the type of soil or aquifer material, the location of the study, and data on environmental conditions for the K_d determination, including (as available) pH, particulate (solid) organic carbon content (POC), dissolved organic carbon content (DOC), iron oxide (FeOx) and aluminum oxide (AlOx) content, percent clay, and cation exchange capacity (CEC). Data for these properties were collected from the cited references when available and entered into the database. Blank entries indicate that the information was not available. Table H-18 provides, for the identical list of metals, an indication of whether the value is relevant to soil or to aquifer material, the pH, extraction fluid (extractant), and experimental method (e.g., batch, column, field study). Comments are provided that describe how data were extracted or processed and special aspects of the study.

H.6 Uncertainty in K_d Values

Partition coefficients reported in the literature and presented in this K_d database are subject to numerous sources of uncertainty. Many previous studies have demonstrated that, in a variety of soils and for a variety of metals, partition coefficients vary with pH and with the concentration of sorbing phases in the soil matrix (e.g., weight percent organic matter content, weight percent hydrous ferric oxides, and corresponding oxides of aluminum and manganese) (Janssen et al., 1997; Hassan and Garrison, 1996; Bangash and Hanif, 1992; Anderson and Christensen, 1988). It is well known that dissolved ligands present in soil porewater (e.g., dissolved organic matter, anthropogenic organic acids) may complex with metals, reducing their propensity for sorption in proportion to the concentration of the ligands (Christensen et al., 1996). Within the population of soils, the natural variability in soil pH and in the composition of soil and its associated porewater results in variation in K_d over orders of magnitude, even for a single metal. For this reason, any comprehensive compilation of K_d values selected from the literature should present values that define a distribution. In fact, for a particular metal, K_d depends on these and other characteristics of the soil/porewater system, and, in a nationwide risk assessment, it is desirable to sample the national population of soil/porewater systems to obtain a frequency distribution of K_d.

Unfortunately, the collection of soil/porewater systems chosen for study by various researchers and reported in the literature almost certainly does not represent the national population of such systems, and collections of K_d values obtained from the literature almost certainly do not represent the true national frequency distribution of K_d for a particular metal. Furthermore, the degree to which the soil systems reported in the literature adequately represent the population of soils varies greatly among the different metals for which K_d values have been obtained. The development of frequency distributions of K_d for this analysis is described in Section H.5. For the empirical treatment, the collected K_d values were simply assumed to represent the true frequency distribution. In the loguniform treatment, the average of the collected log K_d values was assumed to define a central tendency value, and the minimum and maximum were established as 1.5 log units below and above this value. For any particular metal, the degree to which either method of establishing the frequency distribution of K_d is faithful to the true national frequency distribution of K_d, as it reflects the population of soil/porewater systems, is unknown. Qualitatively, it may be supposed that the frequency distributions for K_d represented by the empirical method are more nearly representative of the true frequency distributions because they include more sampled K_d values.

Apart from uncertainties in representing the expected variations in K_d that arise from variation in soil/aquifer properties, there are significant uncertainties associated with individual K_d values. Sources of uncertainty in individual literature K_d values include:

- Detection limits in measuring metal concentrations may result in limiting the observed maximum K_d value.

- Equilibrium conditions may not have prevailed in the experiment for measuring media concentrations. Most batch experiments are carried out over a time span of 1 or 2 days. Equilibrium may or may not have been attained, and nonequilibrium processes that were unaccounted for may have occurred.

- Some variability in collected K_d values may reflect variability in the different methods of measurement (e.g., batch experiments, measurements from natural soil and associated porewater, calculation from tracer/retardation studies).

- Some variability in collected K_d values may reflect variability in extractants used in batch tests. Some researchers used soil porewater or groundwater as the extractant. Others used distilled water or a solution of electrolyte. The modeling in which these K_d values are to be used may implicitly prescribe an extractant that is dissimilar to any used in literature studies (e.g., landfill leachate).

- Some uncertainty in the reported K_d values is associated with uncontrolled or unknown redox conditions during the course of experimental measurements, especially for redox-sensitive metals (e.g., Cr, As, Se).

- There is uncertainty in the K_d values due to neglecting the impact of total system concentration of metal on the magnitude of K_d. Numerous studies have documented the dependence of K_d on total metal concentration—K_d tends to decrease as the total metal concentration increases. No attempt has been made in this compilation of literature values to investigate or represent the dependence of K_d on metal concentration. Instances in cited references of the use of Freundlich isotherms to represent such a dependence have been treated by computing the K_d appropriate for a dissolved metal concentration of 1 ppm. The K_d values compiled here are likely to be more representative of those in systems with low metal concentration than systems with high metal concentration.

Finally, the magnitude of the uncertainty in K_d values presented in this database of literature values should be viewed as having a significant metal-dependent component. As noted already, several metals have been more widely studied (e.g., Cd, As, Pb). For some of the metals of interest in this study, most notably Sb, there is very little partitioning data available for soil and groundwater systems. In addition, some sources of uncertainty listed above are associated with metal-specific phenomena (e.g., detection limits, redox transformations, propensity for dependence of K_d on metal concentration).

H.7 Summary

The following is a brief summary of the distributions used in this risk assessment on a metal-by-metal basis.

- ***Antimony.*** Antimony is characterized by four oxidation states (-III, 0, III, and V). In oxidizing environments, $Sb(OH)_6^-$ is the dominant species for pH values greater than 3. The anionic character of antimony suggests that it would not be highly sorbed under alkaline or oxidizing conditions. However, as the pH decreases to weakly acidic conditions, adsorption reactions may increase in importance. Two measured K_d values were found in the scientific literature for antimony and a loguniform distribution was developed.

- ***Barium.*** Barium may be released to the environment naturally through the weathering of rocks and minerals or anthropogenically in association with mining, refining, production of barium and barium chemicals, and fossil fuel combustion. Once released to the environment, barium exists in one oxidation state (II). Barium mobility is largely controlled by sorption and precipitation reactions. The cation exchange capacity of the soil largely controls the retention of barium in soils. The larger the cation exchange capacity, the more likely barium will be immobilized in the soils. Barium can form precipitates in the presence of carbonate, sulfate, and phosphate. The two most important precipitates under environmental conditions are barium carbonate ($BaCO_3$) and barium sulfate ($BaSO_4$). Hence, soils with high calcium carbonate content and/or elevated concentrations of sulfate ions limit the mobility of barium.

  Only two measured K_d values were compiled from the scientific literature for barium. Both values were reported in the same study. One value (42.5 L/kg) was measured in a sandy soil system with a pH equal to 4.8. The second value (1,355 L/kg) was measured in a sandy loam soil system with a pH equal to 7.8. Because less than five measured values were compiled from the scientific literature, a loguniform distribution was developed for barium.

- ***Cadmium.*** Cadmium may be present in soil as free cadmium compounds or in solution as the Cd^{2+} ion dissolved in interstitial water. Cadmium sorption is pH dependent. The effect of pH on cadmium sorption is influenced by the solution:solid ratio, cadmium concentrations, and the concentration of competing constituents such as calcium, magnesium, and other trace metal cations, which decrease the sorption potential for cadmium. The soil organic fraction does not demonstrate marked affinity for cadmium.

  There was a preponderance of measured K_d values reported for cadmium. A total of 102 values were compiled from 19 references. The K_d values ranged from a minimum of 2 L/kg for aquifer material (pH = 4.9) to a maximum of 18,263 L/kg for soils (pH = 6.4).

- ***Cobalt.*** Cobalt is present in the environment in one oxidation state (II). Cobalt mobility in soils is dependent on pH and the presence of complexing agents. Cobalt sorption tends to increase as a function of increasing pH. The presence of complexing agents may increase the mobility of cobalt in the soils.

  Twenty K_d values were compiled from eight sources. Twelve of the twenty K_d values characterized aquifer systems ranging from heavy clay (14,000 L/kg; pH = 8) to sandy till (140 L/kg; pH = 6.4). The remaining 8 K_d values characterized soil systems that ranged from illitic soil (4,120 L/kg; pH = 8) to agricultural (1,735 L/kg; pH = 5.85) and forest soils (41 L/kg; pH = 3.7).

- ***Copper.*** Copper is not generally mobile in the environment. Most copper in soils is strongly adsorbed and held in the upper few centimeters of the soil. Copper will adsorb to organic matter, carbonate minerals, clays, and hydrous iron-manganese oxides. Organic matter content, pH, and ionic strength are the key parameters affecting adsorption. Adsorption increases with increasing pH.

  Twenty-two K_d values were compiled from two scientific sources. Of the 22 values, 20 were obtained from a single reference and characterized soils from the Netherlands. Of these soils, the minimum K_d value was reported as 25 L/kg (median pH of the 20 soils = 6.4; 2.8 wt% particulate organic matter) and the maximum value was reported as 4,318 L/kg (median pH of the 20 soils = 6.4; 2.8 wt% particulate organic matter). The remaining two values characterized sand (155 L/kg; pH = 4.8; 1.75 wt% particulate organic matter) and sandy loam (500 L/kg; pH = 7.8; 2.25 wt% particulate organic matter).

- ***Chromium.*** Chromium is characterized by multiple oxidation states. Trivalent chromium, Cr(III), and hexavalent chromium, Cr(VI), can both exist in natural systems; however, chromium occurs predominantly in the trivalent state in soils (as insoluble $Cr_2O_3 \cdot nH_2$)). Multiple oxidation states increase the complexity in predicting chromium behavior in the environment. Factors that influence transport through soils include pH, oxidation potential, ion exchange capacity, and interstitial pore size.

  One aspect of the literature search was to compile K_d values specific to oxidation state. Hence, K_d values were compiled for both Cr(III) and Cr(VI). Twenty-five values were collected from four literature sources for Cr(III) and 20 values were collected from 11 literature sources for Cr(VI).

  All 25 K_d values collected for trivalent chromium characterized soils. The majority of the samples were reported in a single reference. The K_d ranged from 25 L/kg (sandy loam; pH = 7.8) to 24,217 L/kg (Horizon R from Netherlands; median pH of the 20 soils = 6.4).

  Two of the twenty K_d values for hexavalent chromium characterized alluvial aquifer material with pH equal to 6.8. One value equaled 5.3 L/kg and the second value equaled 52 L/kg. The values reported for soil samples ranged from 0.2 L/kg (vadose zone soils; pH not specified) to 1,729 L/kg (fine sand; pH = 8.2).

- ***Lead.*** In the environment, the divalent (II) form of lead is the stable species. Lead sorbs strongly to organic matter in soils and, as consequence, lead is relatively immobile in soils.

Thirty-nine K_d values were collected from eight sources. Of the 39 values, five characterized sedimentary aquifer materials. Of these values, the K_d ranged from 20 L/kg (pH = 2) to 4,000 L/kg (pH = 7). The remaining 34 values characterized soil materials and ranged from 17 L/kg (acidic soil; pH = 4) to 67,856 L/kg (Soil T from Netherlands; median pH of the 20 soils = 6.4; 2.8 wt% particulate organic matter).

- ***Mercury.*** Mercury is readily sorbed to soil substrates. It is strongly sorbed to humic materials in soils characterized by pH values equal to or greater than 4. It is also sorbed to iron oxides and clay minerals. Inorganic mercury sorbed to particulate material is not readily desorbed, and, as a consequence, leaching is relatively insignificant. Chloride concentrations may be as important as pH in determining mercury mobility.

  Nine K_d values were compiled from five sources for divalent mercury. Two of the nine K_d values characterized aquifer material. One value equaled 0.22 L/kg (sediment from the Bridgeton Formation and Cohansey Sand; pH = 4.5) and the second value equaled 2.2 L/kg (natural quartz sand from Rhine aquifer; pH not specified). The values reported for soil samples ranged from 0.78 L/kg (New Jersey Coastal Plain soils; pH = 4.5) to10,526 L/kg (soil; pH not specified).

- ***Nickel.*** Nickel is strongly adsorbed to soil substrates. Amorphous iron and magnesium oxides, and to a lesser extent clay minerals, are the most important adsorbents in soil. The degree to which nickel is adsorbed is dependent upon a number of factors, including soil pH, soil type and texture, organic matter content, concentration of competing ions, and concentration of complexing agents. Soil pH is the most important factor controlling nickel adsorption. Adsorption decreases as a function of decreasing pH. Most soils have an extremely high affinity for nickel and, once sorbed, nickel is difficult to desorb, thus limiting nickel’s availability and mobility in the environment.

  Forty values were collected from four sources for nickel. Of the 40 values, 19 characterized aquifer materials. Of these values, the K_d ranged from 3 L/kg (Rabis Baek sand; pH = 4.9; 0.482 wt% particulate organic matter) to 7,250 L/kg (Gunderup 2 aquifer sand from Denmark; pH = 8.75). The remaining 21 values characterized soil materials and ranged from 49.5 L/kg (sand; pH = 4.8) to 5,749 L/kg (Soil R from Netherlands; median pH of the 20 soils = 6.4; 2.8 wt% particulate organic matter).

- ***Selenium***. Selenium exists in a number of different forms, including elemental selenium, selenides, selenites, selenates, and organic selenium. Elemental selenium (Se^0) is formed by bacteria, fungi, and algae, which are capable of reducing selenites and selenates. Elemental selenium occurs under anerobic conditions and is moderately stable in soils. Selenides predominate in acidic soils and soils with high organic content. They are also relatively stable and insoluble. Selenites are thermodynamically stable under reducing conditions, but may exist under oxidizing conditions as well. They are stable in alkaline to mildly acidic environments. Although they are soluble, they sorb onto iron oxides and organic matter, thereby limiting their mobility in the environment. Selenate is the predominant species at pH values greater than 6.5 and under oxidizing conditions. It is characterized as being soluble and having a low sorption potential. It is readily available for uptake by plants. A variety of organic complexes may exist. These complexes are most prevalent in high organic soils.

One of the objectives of the literature search was to provide unique K_d values for all relevant oxidation states. Although 14 K_d values were compiled for selenium from the literature, all 14 values were reported for selenite (IV). The K_d values ranged from 2.17 L/kg (soil; pH = 8.1) to 46.7 L/kg (soil; pH = 8.3).

- ***Silver.*** Silver occurs in the environment in many different species. The monovalent (I) species is the most toxic and most frequently studied. There is a strong affinity between silver and soil organic matter. Once sorbed to the soil substrate, silver is not readily remobilized into solution.

  Nine K_d values were compiled for silver from four references. The majority of the K_ds (7 out of 9) characterized soil systems ranging from silty clay (pH = 6) to sandy loam (pH = 5.9 and 7.8). The remaining two values characterized aquifer materials, including one clay and one gravel system. The minimum K_d for silver equaled 26.8 L/kg (contaminated soil from silver mining area; sandy loam; pH = 5.9; 6.5 wt% particulate organic matter). The maximum K_d value equaled 6,700 L/kg (London clay; pH = 8).

- ***Tin.*** Tin is present in the environment as divalent cationic ions (Sn^{2+}) and as quadrivalent cationic ions (Sn^{4+}). Although the sorption behavior of tin has not been studied extensively, it is expected that tin would generally sorb to soils and sediment.

  Only two K_d values were obtained from the scientific literature for tin. The lesser of the two values equaled 2,150 L/kg and characterized a sandy system with a pH of 4.8. The greater of the two values equaled 7,750 L/kg and characterized a sandy loam system with a pH of 7.8. Because only two values were compiled, a loguniform distribution was used for tin.

- ***Zinc.*** Zinc occurs primarily in the divalent (II) oxidation state in the environment. The mobility of zinc in soils depends on the solubility of the zinc species present and on the physicochemical properties of the soil. The predominant adsorbent surfaces controlling zinc mobility are manganese and iron oxides.

  Forty K_d values were compiled from seven scientific references for zinc. Of the 40 values, 11 characterized aquifer conditions. The K_ds ranged from a minimum value of 2.7 L/kg for sandy glacial outwash sediment with a pH equal to 5.3 to a maximum value of 28,000 L/kg for heavy clay aquifer material (pH equal to 8).

The remaining 29 K_d values characterized soil conditions. The K_ds ranged from a minimum value of 6 L/kg (Soil M from Netherlands; median pH of the 20 soils = 6.4; 2.8 wt% particulate organic matter) to a maximum value of 6,762 (Soil S from Netherlands; median pH of the 20 soils = 6.4; 2.8 wt% particulate organic matter).

	OAR	HWIR
Number of values	174	3,737
Number of references	7	6
Common references	2	2
Minimum value	0.5	12
Median	122	710
Mean	227	1,881
Maximum value	4,360	18,263
Standard deviation	587	3,355
Coefficient of variation	2.6	1.8

HWIR = Hazardous Waste Identification Rule.
OAR = Office of Air and Radiation

References Common to Both Studies

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Figure H-1. K_d Comparison for Cadmium (L/kg)

(continued)

OAR Unique References

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Figure H-1. (continued)

	OAR	HWIR
Number of values	22	3
Number of references	6	1
Common references	0	0
Minimum value	0.25	0.5
Median	44	27
Mean	346	25
Maximum value	2,905	47
Standard deviation	716	23
Coefficient of variation	2.1	0.9

HWIR = Hazardous Waste Identification Rule.
OAR = Office of Air and Radiation

References Common to Both

[NONE]

HWIR Unique References

Hassan, S. M. and A. W. Garrison, 1996. Distribution of chromium species between soil and porewater. *Chemical Speciation and Bioavailability*, 8(3/4):85-103. [Ha96b]

OAR Unique References

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Figure H-2. K_d Comparison for Chromium (L/kg)

	OAR	HWIR
Number of values	14	31
Number of references	4	4
Common references	2	2
Minimum value	19	14
Median	3,500	12,514
Mean	15,444	21,572
Maximum value	79,000	67,856
Standard deviation	24,710	22,789
Coefficient of variation	1.6	1.1

HWIR = Hazardous Waste Identification Rule.
OAR = Office of Air and Radiation

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Figure H-3. K_d Comparison for Lead (L/kg)

Table: Export
Description: Soil Kd table

Field Name	Type	Size	Description
ID	Long Integer	4	unique identifier (key field)
Metal	Text	255	metal (elemental symbol)
Species	Text	255	metal identification (elemental symbol plus oxidation state)
RefIndex	Text	255	unique reference index
Medium	Text	255	substrate medium (soil, aquifer, waste)
MediaDescription	Text	255	description for medium (optional)
Depth(m)	Text	255	depth below ground surface in meters (optional)
Location	Text	255	location (city, state or country if foreign)
Kd_L/kg	Double	8	selected Kd measurement in liters per kilogram
LogKd	Double	8	logarithm (base 10) of Kd value
Uncertainty_(L/kg)	Text	255	standard deviation on Kd (optional)
Cd(mg_w/L_w)	Double	8	dissolved metal concentration in milligrams per liter (optional)
Cs(mg_s/kg_s)	Double	8	sorbed metal concentration in milligrams per liter (optional)
Ctot(mg/L)	Double	8	total metal concentration in milligrams per liter (optional)
Ctot(mg/kg)	Double	8	total metal concentration in milligrams per kilogram (optional)
pH	Double	8	pH for measured value (optional)
POC_wt%	Double	8	solid or total organic carbon for medium in weight percent optional
DOC	Double	8	dissolved organic carbon for extractant solution (optional)
DOC_units	Text	255	units for DOC (mg/L, mmol/L, etc.) (required only when DOC is filled)
FeOx	Double	8	hydrous iron oxides / hydroxides for medium (optional)
FeOx_units	Text	255	units for FeOx (wt%, mmol/kg, etc.) (required only when FeOx is filled)
AlOx	Double	8	hydrous aluminum oxides / hydroxides for medium (optional)
AlOx_units	Text	255	units for AlOx (wt%, mmol/kg, etc.) (required only when AlOx is filled)
Clay_wt%	Double	8	clay content of medium (weight percent) (optional)
CEC	Double	8	cation exchange capacity of medium (optional)
CECunits	Text	255	units for CEC (required only when CEC is filled)
Extractant	Text	255	extraction solution used for measurements (groundwater, 0.1N NaNO3, etc.)
Method	Text	255	method used to measure Kd (batch, column, field, etc.)
Comments	Memo	0	comments on any of the above (highlight selection criteria and any unusual or unique situations)

Figure H-4. Data Dictionary

Table H-1. K_d Data Statistics

Metal	No. of Kd values used	No. of References	Mean	Std. Dev.	Median	Min.	Max.
Ag	9	4	1,805.24	2,144.93	1,200	26.8	6,700
As	35	10	2,363.82	4,022.42	225	0.005	20,412
B	34	6	1.39	1.07	1.165	0.06	3.99
Ba	2	1	698.75	928.08	698.75	42.5	1,355
Be	2	1	5,186.25	6,807.67	5,186.25	372.5	10,000
Cd	102	19	935.50	2,196.15	202.85	2	18,263
Co	20	8	2,123.15	3,259.10	935	19	14,000
Cr(III)	25	4	7,696.44	7,038.37	5,977	25	24,217
Cr(VI)	20	11	305.78	571.59	26.9	0.2	1,729
Cu	22	2	669.68	919.08	476	25	4,318
Hg	9	5	4,542.54	4,185.96	4,500	0.22	10,526.7
Mn	12	4	536.33	1,155.32	113	34	4,100
Mo	5	4	66.10	81.59	10.56	2.75	162.5
Ni	40	4	1,444.46	1,816.82	445	3	7,250
Pb	39	8	18,599.21	22,163.92	5,310	14	67,856
Sb	2	1	12.50	2.12	12.5	11	14
Se	14	6	23.09	12.36	24.76	2.17	46.7
Sn	2	1	4,950.00	3,959.80	4,950	2,150	7,750
V	2	1	202.50	180.31	202.5	75	330
Zn	40	7	3,584.54	5,324.70	2,019.5	2.7	28,000

Table H-2. Empirical K_d Distributions for Silver

Metal	Kd_L/kg	Rank	CDF
Ag	13.4		0
Ag	26.8	1	0.1
Ag	137.1	2	0.2
Ag	390	3	0.3
Ag	650	4	0.4
Ag	1200	5	0.5
Ag	1250	6	0.6
Ag	2570	7	0.7
Ag	3323	8	0.8
Ag	6700	9	0.9
Ag	10077		1

Table H-3. Empirical K_d Distributions for Arsenic

Metal	Kd_L/kg	Rank	CDF
As	0.0025		0
As	0.005	1	0.03
As	1.13	2	0.06
As	1.86	3	0.08
As	2.97	4	0.11
As	10.4	5	0.14
As	12	6	0.17
As	13	7	0.19
As	18.8	8	0.22
As	19.4	9	0.25
As	33.2	10	0.28
As	45	11	0.31
As	67	12	0.33
As	90	13	0.36
As	97	14	0.39
As	120	15	0.42
As	125	16	0.44
As	158	17	0.47
As	225	18	0.5
As	804	19	0.53
As	1362	20	0.56
As	1502	21	0.58
As	2015	22	0.61
As	2109	23	0.64
As	2289	24	0.67
As	2521	25	0.69
As	2905	26	0.72
As	3127	27	0.75
As	3794	28	0.78
As	3829	29	0.81
As	5313	30	0.83
As	6075	31	0.86
As	6649	32	0.89
As	7243	33	0.92
As	9745	34	0.94
As	20412	35	0.97
As	31079		1

Table H-4. Empirical K_d Distributions for Boron

Metal	Kd_L/kg	Rank	CDF
B	0.033		0
B	0.06	1	0.03
B	0.087	2	0.06
B	0.125	3	0.09
B	0.162	4	0.11
B	0.32	5	0.14
B	0.35	6	0.17
B	0.409	7	0.2
B	0.421	8	0.23
B	0.62	9	0.26
B	0.86	10	0.29
B	0.89	11	0.31
B	0.93	12	0.34
B	0.94	13	0.37
B	0.97	14	0.4
B	1.08	15	0.43
B	1.14	16	0.46
B	1.15	17	0.49
B	1.18	18	0.51
B	1.24	19	0.54
B	1.29	20	0.57
B	1.35	21	0.6
B	1.37	22	0.63
B	1.4	23	0.66
B	1.52	24	0.69
B	1.53	25	0.71
B	1.93	26	0.74
B	1.93	27	0.77
B	2.16	28	0.8
B	2.34	29	0.83
B	2.53	30	0.86
B	3.33	31	0.89
B	3.58	32	0.91
B	3.92	33	0.94
B	3.99	34	0.97
B	4.06		1

Table H-5. Empirical K_d Distributions for Cadmium

Metal	Kd_L/kg	Rank	CDF
Cd	1		0
Cd	2	1	0.01
Cd	5.5	2	0.02
Cd	6	3	0.03
Cd	10.47	4	0.04
Cd	11	5	0.05
Cd	12	6	0.06
Cd	12	7	0.07
Cd	13.9	8	0.08
Cd	14	9	0.09
Cd	14	10	0.1
Cd	14	11	0.11
Cd	14.4	12	0.12
Cd	15	13	0.13
Cd	16.82	14	0.14
Cd	19.3	15	0.15
Cd	20.42	16	0.16
Cd	21	17	0.17
Cd	22.1	18	0.17
Cd	23.9	19	0.18
Cd	25	20	0.19
Cd	26.3	21	0.2
Cd	28.8	22	0.21
Cd	30.1	23	0.22
Cd	32	24	0.23
Cd	33.88	25	0.24
Cd	38	26	0.25

(continued)

Table H-5. (continued)

Metal	Kd_L/kg	Rank	CDF
Cd	40	27	0.26
Cd	46.8	28	0.27
Cd	52.5	29	0.28
Cd	52.7	30	0.29
Cd	62.8	31	0.3
Cd	69	32	0.31
Cd	80	33	0.32
Cd	84.3	34	0.33
Cd	87.1	35	0.34
Cd	91.2	36	0.35
Cd	97	37	0.36
Cd	97.9	38	0.37
Cd	102	39	0.38
Cd	113.2	40	0.39
Cd	133.3	41	0.4
Cd	144	42	0.41
Cd	152.1	43	0.42
Cd	159	44	0.43
Cd	175	45	0.44
Cd	180	46	0.45
Cd	181.8	47	0.46
Cd	186.6	48	0.47
Cd	200	49	0.48
Cd	200	50	0.49
Cd	201.5	51	0.5
Cd	204.2	52	0.5
Cd	225	53	0.51

(continued)

Table H-5. (continued)

Metal	Kd_L/kg	Rank	CDF
Cd	250	54	0.52
Cd	255	55	0.53
Cd	266.7	56	0.54
Cd	274.2	57	0.55
Cd	288.4	58	0.56
Cd	300	59	0.57
Cd	303.2	60	0.58
Cd	368.1	61	0.59
Cd	461.8	62	0.6
Cd	475	63	0.61
Cd	488.4	64	0.62
Cd	494.3	65	0.63
Cd	500	66	0.64
Cd	532	67	0.65
Cd	560	68	0.66
Cd	603	69	0.67
Cd	640	70	0.68
Cd	660	71	0.69
Cd	670	72	0.7
Cd	710	73	0.71
Cd	720	74	0.72
Cd	755	75	0.73
Cd	755.1	76	0.74
Cd	769.1	77	0.75
Cd	770	78	0.76
Cd	780	79	0.77
Cd	948	80	0.78

(continued)

Table H-5. (continued)

Metal	Kd_L/kg	Rank	CDF
Cd	974	81	0.79
Cd	1000	82	0.8
Cd	1010	83	0.81
Cd	1078	84	0.82
Cd	1378	85	0.83
Cd	1386.8	86	0.83
Cd	1594.9	87	0.84
Cd	1610	88	0.85
Cd	1700	89	0.86
Cd	1770	90	0.87
Cd	2000	91	0.88
Cd	2175	92	0.89
Cd	2200	93	0.9
Cd	2600	94	0.91
Cd	3549	95	0.92
Cd	4360	96	0.93
Cd	4653	97	0.94
Cd	5049	98	0.95
Cd	5828	99	0.96
Cd	6298	100	0.97
Cd	6446	101	0.98
Cd	18263	102	0.99
Cd	30080		1

Table H-6. Empirical K_d Distributions for Cobalt

Metal	Kd_L/kg	Rank	CDF
Co	9.5		0
Co	19	1	0.05
Co	41	2	0.1
Co	120	3	0.14
Co	136	4	0.19
Co	140	5	0.24
Co	160	6	0.29
Co	232	7	0.33
Co	400	8	0.38
Co	410	9	0.43
Co	880	10	0.48
Co	990	11	0.52
Co	1430	12	0.57
Co	1735	13	0.62
Co	1800	14	0.67
Co	2200	15	0.71
Co	3700	16	0.76
Co	4120	17	0.81
Co	4500	18	0.86
Co	5450	19	0.9
Co	14000	20	0.95
Co	22550		1

Table H-7. Empirical K_d Distributions for Chromium (III)

Metal	Kd_L/kg	Rank	CDF
Cr(III)	12.5		0
Cr(III)	25	1	0.04
Cr(III)	360	2	0.08
Cr(III)	524	3	0.12
Cr(III)	536	4	0.15
Cr(III)	711	5	0.19
Cr(III)	2364	6	0.23
Cr(III)	2418	7	0.27
Cr(III)	2747	8	0.31
Cr(III)	3799	9	0.35
Cr(III)	4219	10	0.38
Cr(III)	4711	11	0.42
Cr(III)	5075	12	0.46
Cr(III)	5977	13	0.5
Cr(III)	6746	14	0.54
Cr(III)	7933	15	0.58
Cr(III)	8116	16	0.62
Cr(III)	8906	17	0.65
Cr(III)	9159	18	0.69
Cr(III)	9519	19	0.73
Cr(III)	11063	20	0.77
Cr(III)	11992	21	0.81
Cr(III)	19796	22	0.85
Cr(III)	20665	23	0.88
Cr(III)	20833	24	0.92
Cr(III)	24217	25	0.96
Cr(III)	27601		1

Table H-8. Empirical K_d Distributions for Chromium (VI)

Metal	Kd_L/kg	Rank	CDF
Cr(VI)	0.1		0
Cr(VI)	0.2	1	0.05
Cr(VI)	0.5	2	0.09
Cr(VI)	1	3	0.14
Cr(VI)	2	4	0.18
Cr(VI)	5.3	5	0.23
Cr(VI)	6	6	0.27
Cr(VI)	7	7	0.32
Cr(VI)	8	8	0.36
Cr(VI)	10	9	0.41
Cr(VI)	22	10	0.45
Cr(VI)	26.9	11	0.5
Cr(VI)	46.5	12	0.55
Cr(VI)	50	13	0.59
Cr(VI)	52	14	0.64
Cr(VI)	100	15	0.68
Cr(VI)	110	16	0.73
Cr(VI)	288	17	0.77
Cr(VI)	1000	18	0.82
Cr(VI)	1372	19	0.86
Cr(VI)	1585	20	0.91
Cr(VI)	1729	21	0.95
Cr(VI)	1873		1

Table H-9. Empirical K_d Distributions for Copper

Metal	Kd_L/kg	Rank	CDF
Cu	15		0
Cu	25	1	0.04
Cu	35	2	0.09
Cu	38	3	0.13
Cu	67	4	0.17
Cu	88	5	0.22
Cu	92	6	0.26
Cu	109	7	0.3
Cu	135	8	0.35
Cu	155	9	0.39
Cu	322	10	0.43
Cu	452	11	0.48
Cu	500	12	0.52
Cu	529	13	0.57
Cu	701	14	0.61
Cu	838	15	0.65
Cu	874	16	0.7
Cu	874	17	0.74
Cu	986	18	0.78
Cu	1033	19	0.83
Cu	1253	20	0.87
Cu	1309	21	0.91
Cu	4318	22	0.96
Cu	7327		1

Table H-10 . Empirical K_d Distributions for Mercury

Metal	Kd_L/kg	Rank	CDF
Hg	0.11		0
Hg	0.22	1	0.1
Hg	0.78	2	0.2
Hg	2.2	3	0.3
Hg	1924.4	4	0.4
Hg	4500	5	0.5
Hg	7600	6	0.6
Hg	8000	7	0.7
Hg	8328.6	8	0.8
Hg	10526.7	9	0.9
Hg	12724.8		1

Table H-11. Empirical K_d Distributions for Manganese

Metal	Kd_L/kg	Rank	CDF
Mn	32		0
Mn	34	1	0.08
Mn	36	2	0.15
Mn	44	3	0.23
Mn	49	4	0.31
Mn	86	5	0.38
Mn	96	6	0.46
Mn	130	7	0.54
Mn	160	8	0.62
Mn	271	9	0.69
Mn	430	10	0.77
Mn	1000	11	0.85
Mn	4100	12	0.92
Mn	7200		1

Table H-12. Empirical K_d Distributions for Nickel

Metal	Kd_L/kg	Rank	CDF
Ni	1.5		0
Ni	3	1	0.02
Ni	7	2	0.05
Ni	12	3	0.07
Ni	18	4	0.1
Ni	24	5	0.12
Ni	40	6	0.15
Ni	40	7	0.17
Ni	49.5	8	0.2
Ni	115	9	0.22
Ni	130	10	0.24
Ni	185	11	0.27
Ni	236	12	0.29
Ni	243	13	0.32
Ni	250	14	0.34
Ni	292	15	0.37
Ni	310	16	0.39
Ni	350	17	0.41
Ni	376	18	0.44
Ni	420	19	0.46
Ni	440	20	0.49
Ni	450	21	0.51
Ni	744	22	0.54
Ni	1088	23	0.56
Ni	1255	24	0.59
Ni	1285	25	0.61
Ni	1430	26	0.63
Ni	1510	27	0.66
Ni	1660	28	0.68
Ni	1843	29	0.71
Ni	1857	30	0.73
Ni	2163	31	0.76
Ni	2310	32	0.78
Ni	2750	33	0.8
Ni	3151	34	0.83
Ni	4113	35	0.85
Ni	4370	36	0.88
Ni	4510	37	0.9
Ni	4750	38	0.93
Ni	5749	39	0.95
Ni	7250	40	0.98
Ni	8751		1

Table H-13. Empirical K_d Distributions for Lead

Metal	Kd_L/kg	Rank	CDF
Pb	9		0
Pb	14	1	0.025
Pb	19	2	0.05
Pb	19.8	3	0.075
Pb	20	4	0.1
Pb	24.4	5	0.125
Pb	93	6	0.15
Pb	96	7	0.175
Pb	100	8	0.2
Pb	126	9	0.225
Pb	750	10	0.25
Pb	916	11	0.275
Pb	1159	12	0.3
Pb	1326	13	0.325
Pb	1500	14	0.35
Pb	2637	15	0.375
Pb	3428	16	0.4
Pb	3550	17	0.425
Pb	4000	18	0.45
Pb	4250	19	0.475
Pb	5310	20	0.5
Pb	5923	21	0.525
Pb	9000	22	0.55
Pb	12514	23	0.575
Pb	16973	24	0.6
Pb	21000	25	0.625
Pb	22944	26	0.65
Pb	27722	27	0.675
Pb	30000	28	0.7
Pb	34727	29	0.725
Pb	36930	30	0.75
Pb	37379	31	0.775
Pb	42250	32	0.8
Pb	45502	33	0.825
Pb	46000	34	0.85
Pb	59000	35	0.875
Pb	60000	36	0.9
Pb	60000	37	0.925
Pb	60311	38	0.95
Pb	67856	39	0.975
Pb	75401		1

Table H-14. Empirical K_d Distributions for Selenium

Metal	Kd_L/kg	Rank	CDF
Se	1.085		0
Se	2.17	1	0.07
Se	9.25	2	0.13
Se	10.5	3	0.2
Se	10.7	4	0.27
Se	16.5	5	0.33
Se	18.9	6	0.4
Se	23.5	7	0.47
Se	26	8	0.53
Se	27.5	9	0.6
Se	30	10	0.67
Se	32	11	0.73
Se	34.5	12	0.8
Se	35	13	0.87
Se	46.7	14	0.93
Se	58.4		1

Table H-15. Empirical K_d Distributions for Zinc

Metal	Kd_L/kg	Rank	CDF
Zn	1.35		0
Zn	2.7	1	0.02
Zn	6	2	0.05
Zn	23	3	0.07
Zn	33.8	4	0.1
Zn	34	5	0.12
Zn	38	6	0.15
Zn	41	7	0.17
Zn	41	8	0.2
Zn	55.5	9	0.22
Zn	72.5	10	0.24
Zn	73	11	0.27
Zn	154	12	0.29
Zn	422	13	0.32
Zn	604	14	0.34
Zn	994.9	15	0.37
Zn	1278	16	0.39
Zn	1294	17	0.41
Zn	1299	18	0.44
Zn	1756	19	0.46
Zn	1989	20	0.49
Zn	2050	21	0.51
Zn	2245	22	0.54
Zn	2438	23	0.56
Zn	2700	24	0.59
Zn	2800	25	0.61
Zn	3000	26	0.63
Zn	3200	27	0.66
Zn	3698	28	0.68
Zn	5000	29	0.71
Zn	5100	30	0.73
Zn	5112	31	0.76
Zn	5472	32	0.78
Zn	5600	33	0.8
Zn	5667	34	0.83
Zn	6226	35	0.85
Zn	6762	36	0.88
Zn	9100	37	0.9
Zn	14000	38	0.93
Zn	15000	39	0.95
Zn	28000	40	0.98
Zn	41000		1

Table H-16. Loguniform K_d Distributions Used in Model Runs

Metal	Count	Distribution Type	Min Kd	Max Kd
Ba	2	loguniform	7.6	7586
Be	2	loguniform	61	60954
Mo	5	loguniform	0.68	682
Sb	2	loguniform	0.39	393
Sn	2	loguniform	129	128825
V	2	loguniform	5.0	5012

Table H-17. Measured K_d Values: Experimental Conditions

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
9	Ag	Ba92	Listing	London clay	England	6700	3.83	8		6	mg/L							
3	Ag	Jo86	HWIR	shallow soil	Wales	3323	3.52	5.8	7.5									
8	Ag	Ba92	Listing	gravel	England	2570	3.41	7.8										
5	Ag	Ge82	Listing	sandy loam	Netherlands	1250	3.1	7.8	2.25									
4	Ag	Sz95	HWIR	soil		1200	3.08											
6	Ag	Ge82	Listing	sand	Netherlands	650	2.81	4.8	1.75									
7	Ag	Jo86	HWIR	peaty soil	Wales	390	2.59	4.2	39									
1	Ag	Jo86	HWIR	gleyed silty clay	Wales	137	2.14	6	3.6									
2	Ag	Jo86	HWIR	sandy loam	Wales	26.8	1.43	5.9	6.5									
39	As(V)	Ja97	HWIR	Soil O	Netherlands	20412	4.31	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
42	As(V)	Ja97	HWIR	Soil R	Netherlands	9745	3.99	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
27	As(V)	Ja97	HWIR	Soil C	Netherlands	7243	3.86	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
31	As(V)	Ja97	HWIR	Soil G	Netherlands	6649	3.82	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
26	As(V)	Ja97	HWIR	Soil B	Netherlands	6075	3.78	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
34	As(V)	Ja97	HWIR	Soil J	Netherlands	5313	3.73	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
28	As(V)	Ja97	HWIR	Soil D	Netherlands	3829	3.58	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
30	As(V)	Ja97	HWIR	Soil F	Netherlands	3794	3.58	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
41	As(V)	Ja97	HWIR	Soil Q	Netherlands	3127	3.5	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
29	As(V)	Ja97	HWIR	Soil E	Netherlands	2905	3.46	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
43	As(V)	Ja97	HWIR	Soil S	Netherlands	2521	3.4	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
44	As(V)	Ja97	HWIR	Soil T	Netherlands	2289	3.36	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
37	As(V)	Ja97	HWIR	Soil M	Netherlands	2109	3.32	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
40	As(V)	Ja97	HWIR	Soil P	Netherlands	2015	3.3	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
36	As(V)	Ja97	HWIR	Soil L	Netherlands	1502	3.18	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
25	As(V)	Ja97	HWIR	Soil A	Netherlands	1362	3.13	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
38	As(V)	Ja97	HWIR	Soil N	Netherlands	804	2.91	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
10	As	On96	Listing	glacio-deltaic sediment	Auburn, ME	225	2.35											
35	As(V)	Ja97	HWIR	Soil K	Netherlands	158	2.2	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
23	As(V)	Ge82	Listing	sandy loam	Netherlands	125	2.1	7.8	2.25									
12	As	Ku97a	Listing	clayey silt	Houston, TX	120	2.08	11	0.66	40	mg/L	0.6	wt%	0.5	wt%			
33	As(V)	Ja97	HWIR	Soil I	Netherlands	97	1.99	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
32	As(V)	Ja97	HWIR	Soil H	Netherlands	90	1.95	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
22	As(V)	Is93	HWIR	two soil horizons		67	1.83	5.3	0.34			1.09	wt%					
24	As(V)	Ge82	Listing	sand	Netherlands	45	1.65	4.8	1.75									
18	As	Jo99	Listing	nonirrigated Madison R. valley soil A1	MT	33.2	1.52	8	2.8									
14	As	DOE93	Listing	aquifer sediments	Rifle, CO	19.4	1.29	7.2										
16	As	Jo99	Listing	nonirrigated Madison R. valley soil C	MT	18.8	1.27	8	2.8									
19	As	Jo99	Listing	nonirrigated Madison R. valley soil D1	MT	13	1.11	8	2.8									
21	As(III)	Is93	HWIR	one soil horizon		12	1.08	5.3	0.34			1.09	wt%					

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
15	As	Jo99	Listing	nonirrigated Madison R. valley soil B	MT	10.4	1.02	8	2.8									
13	As	Ku97b	Listing	silty sand	Houston, TX	2.97	0.47	7	0.015			0.14	wt%	0.04	wt%			
17	As	Ca98	Listing	monitoring well sediment	Mexico	1.86	0.27	7										
20	As(III)	Is93	HWIR	one soil horizon		1.13	0.05	5.3	0.34			1.09	wt%					
11	As	Za92	Listing	gravel; carbonate & dolomite	Munich, GDR	0.005	-2.3	7.4										
52	B	El82	Listing	Glendale clay	NM	3.99	0.6	7.57	0.97			0.42	wt%	0.08	wt%	57	35.2	meq/100g
46	B	Go91	Listing	calcareous	Imperial Valley, CA	3.92	0.59		0.83									
50	B	Sa97	Listing	Ustochrept	India	3.58	0.55	8.15	0.53			0.31	%			14		
58	B	El82	Listing	Reagan clay loam	NM	3.33	0.52	7.54	1.1			0.18	wt%	0.09	wt%	27.3	18.5	meq/100g
54	B	El82	Listing	Lea sandy loam	NM	2.53	0.4	7.62	0.57			0.03	wt%	0.07	wt%	14.5	14.1	meq/100g
49	B	Sa97	Listing	Haplustert	India	2.34	0.37	7.15	0.49			0.866	%			45		
53	B	El82	Listing	Harvey sandy loam	NM	2.16	0.33	7.42	0.43			0.09	wt%	0.12	wt%	13.7	14	meq/100g
48	B	Sa97	Listing	Haplustalf	India	1.93	0.29	5	0.46			0.624	%			21		
45	B	El82	Listing	Carjo silt loam	NM	1.93	0.29	6.02	1			0.38	wt%	0.27	wt%	25	16.2	meq/100g
71	B	Mo93	Listing	Soil 3	W. Bengal, India	1.53	0.18											
63	B	Mo93	Listing	Soil 10	W. Bengal, India	1.52	0.18											

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
67	B	Mo93	Listing	Soil 14	W. Bengal, India	1.4	0.15											
65	B	Mo93	Listing	Soil 12	W. Bengal, India	1.37	0.14											
47	B	Sa97	Listing	Calciorthent	India	1.35	0.13	7.52	0.34			0.106	%			50		
68	B	Mo93	Listing	Soil 15	W. Bengal, India	1.29	0.11											
62	B	Mo93	Listing	Soil 1	W. Bengal, India	1.24	0.09											
70	B	Mo93	Listing	Soil 2	W. Bengal, India	1.18	0.07											
66	B	Mo93	Listing	Soil 13	W. Bengal, India	1.15	0.06											
74	B	Mo93	Listing	Soil 6	W. Bengal, India	1.14	0.06											
75	B	Mo93	Listing	Soil 7	W. Bengal, India	1.08	0.03											
76	B	Mo93	Listing	Soil 8	W. Bengal, India	0.97	-0.01											
77	B	Mo93	Listing	Soil 9	W. Bengal, India	0.94	-0.03											
72	B	Mo93	Listing	Soil 4	W. Bengal, India	0.93	-0.03											
64	B	Mo93	Listing	Soil 11	W. Bengal, India	0.89	-0.05											
73	B	Mo93	Listing	Soil 5	W. Bengal, India	0.86	-0.07											

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlO x	AlOx units	Clay_ wt%	CEC	CEC units
78	B	Ye95	Listing	loess	Israel	0.62	-0.21	7.5	0.55								168	mmol/kg
56	B	El82	Listing	R-28 sand	NM	0.421	-0.38	7.89	0.04			0.21	wt%	0.08	wt%	7.7	8.1	meq/100g
55	B	El82	Listing	Puye sandy loam	NM	0.409	-0.39	6.02	0.45			0.27	wt%	0.14	wt%	10	5.5	meq/100g
60	B	Go91	Listing	clayey loam	Imperial Valley, CA	0.35	-0.46		0.1									
69	B	Mo93	Listing	Soil 16	W. Bengal, India	0.32	-0.49											
57	B	El82	Listing	R-30 sand	NM	0.162	-0.79	7.82	0.04			0.1	wt%	0.07	wt%	5.6	7.8	meq/100g
51	B	El82	Listing	Chem B sand	NM	0.125	-0.9	8	0.02			0.17	wt%	0.06	wt%	5	6.2	meq/100g
59	B	El82	Listing	Tuff loamy sand	NM	0.087	-1.06	7.03	0.17			0.21	wt%	0.08	wt%	3.4	1.6	meq/100g
61	B	Br97	Listing	unconsolidated, conglomerate	Stanton, TX	0.06	-1.22	7.57										
79	Ba(II)	Ge82	Listing	sandy loam	Netherlands	1355	3.13	7.8	2.25									
80	Ba(II)	Ge82	Listing	sand	Netherlands	42.5	1.63	4.8	1.75									
81	Be(II)	Ge82	Listing	sandy loam	Netherlands	10000	4	7.8	2.25									
82	Be(II)	Ge82	Listing	sand	Netherlands	372.5	2.57	4.8	1.75									
167	Cd(II)	Ja97	HWIR	Soil T	Netherlands	18263	4.26	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
166	Cd(II)	Ja97	HWIR	Soil S	Netherlands	6446	3.81	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
165	Cd(II)	Ja97	HWIR	Soil R	Netherlands	6298	3.8	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
153	Cd(II)	Ja97	HWIR	Soil D	Netherlands	5828	3.77	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
155	Cd(II)	Ja97	HWIR	Soil F	Netherlands	5049	3.7	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
163	Cd(II)	Ja97	HWIR	Soil P	Netherlands	4653	3.67	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
147	Cd(II)	De91	OAR	alluvium		4360	3.64	8				2.5	wt%			12.4		

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
156	Cd(II)	Ja97	HWIR	Soil G	Netherlands	3549	3.55	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
173	Cd(II)	Ku91	HWIR	coastal soil	WA	2600	3.41	6	5.4			1.27	wt% Fe					
174	Cd(II)	Ku91	HWIR	coastal soil	WA	2200	3.34	6	7			0.55	wt% Fe					
178	Cd(II)	Ku91	HWIR	coastal soil	WA	2175	3.34	6.5	1.8			1.45	wt% Fe					
145	Cd(II)	Ge82	Listing	sandy loam	Netherlands	2000	3.3	7.8	2.25									
134	Cd(II)	Ch96	Listing	Allerod 1 sand	Denmark	1770	3.25	8.83	0.133							2		
183	Cd(II)	Ch85	HWIR	sandy loam	Denmark	1700	3.23	6.65	0.15			1.65	wt% Fe					
124	Cd(II)	Ch96	Listing	Gunderup 2 sand	Denmark	1610	3.21	8.75	0.292							0		
172	Cd(II)	Le98	Listing	Wan-li loam	Taiwan	1595	3.2	6.51	1.9							11.5	1	meq/100g
105	Cd(II)	An88	HWIR	agricultural Danish soil	Denmark	1386.8	3.14	7.3										
154	Cd(II)	Ja97	HWIR	Soil E	Netherlands	1378	3.14	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
151	Cd(II)	Ja97	HWIR	Soil B	Netherlands	1078	3.03	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
123	Cd(II)	Ch96	Listing	Gunderup 1 sand	Denmark	1010	3	8.87	0.032							1		
148	Cd(II)	De91	OAR	interbed		1000	3	8				3.7	wt%			12		
162	Cd(II)	Ja97	HWIR	Soil O	Netherlands	974	2.99	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
164	Cd(II)	Ja97	HWIR	Soil Q	Netherlands	948	2.98	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
181	Cd(II)	Ch85	HWIR	sand	Denmark	780	2.89	6.65	0.2			0.38	wt% Fe					
175	Cd(II)	Ku91	HWIR	coastal soil	WA	770	2.89	6	1.8			1.45	wt% Fe					
104	Cd(II)	An88	HWIR	agricultural Danish soil	Denmark	769.1	2.89	6.9										
119	Cd(II)	Bu89	OAR	Webster Ap		755.1	2.88	7.6	4.39			0.19	wt%			23.9	48.1	meq/100g

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
152	Cd(II)	Ja97	HWIR	Soil C	Netherlands	755	2.88	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
122	Cd(II)	Ch96	Listing	Finderup 2 sand	Denmark	720	2.86	7.96	0.108							0		
176	Cd(II)	Ku91	HWIR	coastal soil	WA	710	2.85	6	2			0.87	wt% Fe					
127	Cd(II)	Ch96	Listing	Tirstrup 1 sand	Denmark	670	2.83	8.51	0.306							3		
131	Cd(II)	Ch96	Listing	Vorbasse 2 sand	Denmark	660	2.82	8.46	0.01							0		
128	Cd(II)	Ch96	Listing	Tylstrup sand	Denmark	640	2.81	8.01	0.167							4		
150	Cd(II)	Ja97	HWIR	Soil L	Netherlands	603	2.78	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
135	Cd(II)	Ch96	Listing	Allerod 2 sand	Denmark	560	2.75	8.47	0.083							0		
159	Cd(II)	Ja97	HWIR	Soil J	Netherlands	532	2.73	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
125	Cd(II)	Ch96	Listing	Herborg sand	Denmark	500	2.7	7.85	0.213							0		
103	Cd(II)	An88	HWIR	agricultural Danish soil	Denmark	494.3	2.69	6.6										
138	Cd(II)	Ma92	OAR	Soil A		488.4	2.69	6.8								25.2	27.5	meq/100g
177	Cd(II)	Ku91	HWIR	coastal soil	WA	475	2.68	6	1.6			0.35	wt% Fe					
168	Cd(II)	Le98	Listing	Hu-shan farm sand	Taiwan	461.8	2.66	6.89	0.55							6.5	7.3	meq/100g
102	Cd(II)	An88	HWIR	agricultural Danish soil	Denmark	368.1	2.57	6.4										
170	Cd(II)	Le98	Listing	Kuei-jen loam	Taiwan	303.2	2.48	6.38	0.45							9	8.1	meq/100g
179	Cd(II)	Ku91	HWIR	coastal soil	WA	300	2.48	5	1.8			1.45	wt% Fe					
108	Cd(II)	Bu89	OAR	Cecil Ap		288.4	2.46	5.7	0.61			0.1	wt%			8.3	2	meq/100g
101	Cd(II)	An88	HWIR	agricultural Danish soil	Denmark	274.2	2.44	6.2										
90	Cd(II)	Na78	OAR	Hahoterim		266.7	2.43	7.9	0.86								37	meq/100g

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
142	Cd(II)	Za92	Listing	gravel; carbonate & dolomite	Munich, GDR	255	2.41	7.4										
182	Cd(II)	Ch85	HWIR	sand	Denmark	250	2.4	5.5	0.2			0.38	wt% Fe					
184	Cd(II)	Ch85	HWIR	sandy loam	Denmark	225	2.35	5.5	0.15			1.65	wt% Fe					
100	Cd(II)	An88	HWIR	agricultural Danish soil	Denmark	204.2	2.31	6										
146	Cd(II)	Ge82	Listing	sand	Netherlands	201.5	2.3	4.8	1.75									
87	Cd(II)	Na78	OAR	Bet Yizhaq		200	2.3	7.8	0.83								15.4	meq/100g
140	Cd(II)	Al95	HWIR	Boonton loam	NJ	200	2.3	5.12	8.6							6		
110	Cd(II)	Bu89	OAR	Kula Ap1		186.6	2.27	5.9	6.62			1.68	wt%			0.9	22.54	meq/100g
91	Cd(II)	Na78	OAR	Maaban Michael		181.8	2.26	7.6	0.79								31.8	meq/100g
130	Cd(II)	Ch96	Listing	Vorbasse 1 sand	Denmark	180	2.26	6.77	0.011							1		
180	Cd(II)	Ku91	HWIR	coastal soil	WA	175	2.24	4.5	1.8			1.45	wt% Fe					
158	Cd(II)	Ja97	HWIR	Soil I	Netherlands	159	2.2	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
99	Cd(II)	An88	HWIR	agricultural Danish soil	Denmark	152.1	2.18	5.8										
157	Cd(II)	Ja97	HWIR	Soil H	Netherlands	144	2.16	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
89	Cd(II)	Na78	OAR	Gilat		133.3	2.12	8.3	0.23								18.9	meq/100g
98	Cd(II)	An88	HWIR	agricultural Danish soil	Denmark	113.2	2.05	5.6										
160	Cd(II)	Ja97	HWIR	Soil K	Netherlands	102	2.01	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
114	Cd(II)	Bu89	OAR	Olivier Ap		97.9	1.99	6.6	0.83			0.3	wt%			6.2	8.6	meq/100g
133	Cd(II)	Sc88	HWIR	forest soil	Bavaria	97	1.99	3.7								3		

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
112	Cd(II)	Bu89	OAR	Molokai Ap		91.2	1.96	6	1.67			0.19	wt%			28.2	11	meq/100g
118	Cd(II)	Ga80	OAR	Vertic Torrifluvent		87.1	1.94	8.4	1.44			1.07	wt%				60	meq/100g
97	Cd(II)	An88	HWIR	agricultural Danish soil	Denmark	84.3	1.93	5.4										
88	Cd(II)	Na78	OAR	Gevulot		80	1.9	8.2	0.21								8.2	meq/100g
83	Cd(II)	Me94	HWIR	acidic soil	England	69	1.84	4.6	10.5									
96	Cd(II)	An88	HWIR	agricultural Danish soil	Denmark	62.8	1.8	5.2										
111	Cd(II)	Bu89	OAR	Lafitte Ap		52.7	1.72	3.9	11.6			1.19	wt%			17.6	26.9	meq/100g
106	Cd(II)	Bu89	OAR	Alligator Ap		52.5	1.72	4.8	1.54			0.33	wt%			54.7	30.2	meq/100g
95	Cd(II)	An88	HWIR	agricultural Danish soil	Denmark	46.8	1.67	5										
132	Cd(II)	Ch96	Listing	Vorbasse 3 sand	Denmark	40	1.6	5.83	0.072							1		
149	Cd(II)	St86	Listing	Shelocta silt loam	TN	38	1.58											
115	Cd(II)	Ga80	OAR	organic		33.88	1.53	5.2	32.6								33.8	meq/100g
86	Cd(II)	Me94	HWIR	acidic soil	England	32	1.51	3.4	13.3									
94	Cd(II)	An88	HWIR	agricultural Danish soil	Denmark	30.1	1.48	4.7										
113	Cd(II)	Bu89	OAR	Norwood Ap		28.8	1.46	6.9	0.21			0.06	wt%			2.8	4.1	meq/100g
92	Cd(II)	Vu98	Listing	Sava R. alluvial sediment	Croatia	26.3	1.42	5.8	0.5									
143	Cd(II)	Al95	HWIR	Rockaway stony loam	NJ	25	1.4	4.7	0.2							16		

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlO x	AlOx units	Clay_ wt%	CEC	CEC units
171	Cd(II)	Le98	Listing	Niu-chou-pu sandy loam	Taiwan	23.9	1.38	4.81	0.15							12	8.5	meq/100g
169	Cd(II)	Le98	Listing	Hu-tou-pi sandy loam	Taiwan	22.1	1.34	3.96	0.4							10	8.1	meq/100g
161	Cd(II)	Ja97	HWIR	Soil M	Netherlands	21	1.32	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
107	Cd(II)	Ga80	OAR	Boomer, Ultic Haploxeralf		20.42	1.31	5.8	3			8.29	wt%				23.8	meq/100g
93	Cd(II)	An88	HWIR	agricultural Danish soil	Denmark	19.3	1.29	4.4										
139	Cd(II)	Pa99	Listing	fluvioglacial outwash gravels	Burnham, New Zealand	16.82	1.23	7.3	0.23								0.053	me/g
85	Cd(II)	Me94	HWIR	acidic soil	England	15	1.18	4.1	7.9									
120	Cd(II)	Bu89	OAR	Windsor Ap		14.4	1.16	5.3	2.03			0.42	wt%			2.8	2	meq/100g
121	Cd(II)	Ch96	Listing	Finderup 1 sand	Denmark	14	1.15	6.19	0.007							1		
129	Cd(II)	Ch96	Listing	Vejen sand	Denmark	14	1.15	5.66	0.034							1		
141	Cd(II)	Al95	HWIR	Freehold sandy loam	NJ	14	1.15	5.22	0.2							13		
109	Cd(II)	Bu89	OAR	Cecil B		13.9	1.14	5.4	0.26			0.08	wt%			51.2	2.4	meq/100g
144	Cd(II)	Al95	HWIR	Downer loamy sand	NJ	12	1.08	4.8	0.8							8		
84	Cd(II)	Me94	HWIR	acidic soil	England	12	1.08	4	5.7									
136	Cd(II)	Ch96	Listing	Borris sand	Denmark	11	1.04	5.86	0.032							0		
117	Cd(II)	Ga80	OAR	UlticPalexeral		10.47	1.02	6	3.2			1.07	wt%				25	meq/100g
137	Cd(II)	Ch96	Listing	Brande sand	Denmark	6	0.78	5.28	0.028							1		
116	Cd(II)	Bu89	OAR	Spodisol		5.5	0.74	4.3	1.98			0	wt%			3.8	2.7	meq/100g
126	Cd(II)	Ch96	Listing	Rabis Baek sand	Denmark	2	0.3	4.91	0.482							1		

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
197	Co(II)	Mi82	Listing	Soil 5: heavy clay	Finland	14000	4.15	8									25	meq/100g
204	Co(II)	Ta94	Listing	loess	China	5450	3.74	7.5										
198	Co(II)	Mi82	Listing	Soil 6: silty clay	Finland	4500	3.65	7									17	meq/100g
187	Co(II)	Ban92	HWIR	illitic soil	Islamabad, Pakistan	4120	3.61	8	0.25									
189	Co(II)	Ge82	Listing	sandy loam	Netherlands	3700	3.57	7.8	2.25									
192	Co(II)	Mi82	Listing	Soil 1: heavy clay	Finland	2200	3.34	8.2									26	meq/100g
194	Co(II)	Mi82	Listing	Soil 2: heavy clay	Finland	1800	3.26	8.2										meq/100g
188	Co(II)	Ya95	Listing	paddy and upland agricultural soils	Japan	1735	3.24	5.85									107	mmol/kg
203	Co(II)	Ba92	Listing	London clay	England	1430	3.16			6	mg/L							
195	Co(II)	Mi82	Listing	Soil 3: heavy clay	Finland	990	3	8.4									21	meq/100g
193	Co(II)	Mi82	Listing	Soil 10: sandy till	Finland	880	2.94	6.2										meq/100g
196	Co(II)	Mi82	Listing	Soil 4: heavy clay	Finland	410	2.61	8.3									5.7	meq/100g
201	Co(II)	Mi82	Listing	Soil 9: sandy till	Finland	400	2.6	6.8										meq/100g
202	Co(II)	Ha88	Listing	glacial sand	Cumbria, UK	232	2.37	7.3		6.9	mg/L						2.8	meq/100g
199	Co(II)	Mi82	Listing	Soil 7: sandy till	Finland	160	2.2	6.4									2.8	meq/100g
200	Co(II)	Mi82	Listing	Soil 8: sandy till	Finland	140	2.15	6.4									3.2	meq/100g

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
185	Co(II)	Ra96	HWIR		Bhopal, India	136	2.13	8.5	0.57							36		
191	Co(II)	Ra96	HWIR		Tehri, India	120	2.08	6.3	0.69							11		
186	Co(II)	Sc88	HWIR	forest soil	Bavaria	41	1.61	3.7								3		
190	Co(II)	Ge82	Listing	sand	Netherlands	19	1.28	4.8	1.75									
228	Cr(III)	Ja97	HWIR	Soil R	Netherlands	24217	4.38	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
209	Cr(III)	Ha96b	HWIR	loess		20833	4.32	6.2	0.11			9717	mg/kg					
219	Cr(III)	Ja97	HWIR	Soil G	Netherlands	20665	4.32	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
226	Cr(III)	Ja97	HWIR	Soil P	Netherlands	19796	4.3	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
214	Cr(III)	Ja97	HWIR	Soil B	Netherlands	11992	4.08	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
227	Cr(III)	Ja97	HWIR	Soil Q	Netherlands	11063	4.04	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
229	Cr(III)	Ja97	HWIR	Soil S	Netherlands	9519	3.98	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
230	Cr(III)	Ja97	HWIR	Soil T	Netherlands	9159	3.96	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
225	Cr(III)	Ja97	HWIR	Soil O	Netherlands	8906	3.95	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
215	Cr(III)	Ja97	HWIR	Soil C	Netherlands	8116	3.91	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
216	Cr(III)	Ja97	HWIR	Soil D	Netherlands	7933	3.9	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
218	Cr(III)	Ja97	HWIR	Soil F	Netherlands	6746	3.83	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
217	Cr(III)	Ja97	HWIR	Soil E	Netherlands	5977	3.78	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
208	Cr(III)	Ha96b	HWIR	Zahl loam		5075	3.71	6.52	1.92			7182	mg/kg					
212	Cr(III)	Ja97	HWIR	Soil L	Netherlands	4711	3.67	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
222	Cr(III)	Ja97	HWIR	Soil J	Netherlands	4219	3.63	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
220	Cr(III)	Ja97	HWIR	Soil H	Netherlands	3799	3.58	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
213	Cr(III)	Ja97	HWIR	Soil A	Netherlands	2747	3.44	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
221	Cr(III)	Ja97	HWIR	Soil I	Netherlands	2418	3.38	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
224	Cr(III)	Ja97	HWIR	Soil M	Netherlands	2364	3.37	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
206	Cr(III)	Sh91a	HWIR	sandy soil	Canada	711	2.85	5.7	0.313			4646	mg/kg					
207	Cr(III)	Ha96b	HWIR	clay		536	2.73	4.03	3.75			19217	mg/kg					
223	Cr(III)	Ja97	HWIR	Soil K	Netherlands	524	2.72	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
211	Cr(III)	Ge82	Listing	sand	Netherlands	360	2.56	4.8	1.75									
210	Cr(III)	Ge82	Listing	sandy loam	Netherlands	25	1.4	7.8	2.25									
238	Cr(VI)	Wo83	OAR	Hallandale fine sand	FL	1729	3.24	8.2	1.45								0.113	meq/100g
244	Cr(VI)	Ra88	OAR	Holton/Cloudland Series (Bx horizon)	TN	1585	3.2	4.45	0.05			0.435	mmol/g			34	7.3	meq/100g
234	Cr(VI)	Wo83	OAR	organic soil (muck); all layers	FL	1372	3.14	7.2	5.52								0.34	meq/100g
248	Cr(VI)	Sh87	OAR	loam (Chernozem)	Canada	1000	3										60	meq/100g
245	Cr(VI)	Ra88	OAR	Cecil/Pacolet Series (Be horizon)	NC	288	2.46	5.46	0.07			0.266	mmol/g			28	4.4	meq/100g
250	Cr(VI)	Ra85	OAR	Toa Series	PR	110	2.04											
249	Cr(VI)	Sh87	OAR	sand (Regosol)	Canada	100	2										1.6	meq/100g
242	Cr(VI)	St85	Listing	alluvium	Telluride, CO	52	1.72	6.8								0.3		
241	Cr(VI)	Sh87b	OAR	sand (Brunisol) all layers	Canada	50	1.7	5.425									2.19	meq/100g
237	Cr(VI)	Ha96b	HWIR	loess		46.5	1.67	2.52	0.11			9717	mg/kg					
235	Cr(VI)	Ha96b	HWIR	clay		26.9	1.43	2.29	3.75			19217	mg/kg					

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
205	Cr(VI)	Ni94	Listing	fine to silty sands	Woodstock, CN	22	1.34	4.7	1.2									
233	Cr(VI)	Se88	OAR	Cecil Series		10	1	5.1	0.24			10.2	wt%				3.72	meq/100g
247	Cr(VI)	Ra85	OAR	Bayamon Series	PR	8	0.9											
246	Cr(VI)	Ra88	OAR	Kenoma Series (Be+C horizon)	KS	7	0.85	6.92	0.32			0.162	mmol/g			46	28.4	meq/100g
232	Cr(VI)	Se88	OAR	Windsor Series		6	0.78	5.4	0.94			2.2	wt%				1.2	meq/100g
240	Cr(VI)	St85	Listing	alluvium	Telluride, CO	5.3	0.72	6.8										
231	Cr(VI)	Se88	OAR	Olivier Series		2	0.3	6.4	0.99			1.14	wt%				8.31	meq/100g
243	Cr(VI)	Ra88	OAR	Ocala Series (C4 horizon)	NV	1	0	9.4	0.14			0.009	mmol/g			31	35.7	meq/100g
236	Cr(VI)	Ha96b	HWIR	Zahl loam		0.5	-0.3	11.1	1.92			7182	mg/kg					
239	Cr(VI)	Me91	Listing	vadose zone	USA	0.2	-0.7											
270	Cu(II)	Ja97	HWIR	Soil R	Netherlands	4318	3.64	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
267	Cu(II)	Ja97	HWIR	Soil O	Netherlands	1309	3.12	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
271	Cu(II)	Ja97	HWIR	Soil S	Netherlands	1253	3.1	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
260	Cu(II)	Ja97	HWIR	Soil G	Netherlands	1033	3.01	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
269	Cu(II)	Ja97	HWIR	Soil Q	Netherlands	986	2.99	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
263	Cu(II)	Ja97	HWIR	Soil J	Netherlands	874	2.94	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
272	Cu(II)	Ja97	HWIR	Soil T	Netherlands	874	2.94	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
268	Cu(II)	Ja97	HWIR	Soil P	Netherlands	838	2.92	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
256	Cu(II)	Ja97	HWIR	Soil C	Netherlands	701	2.85	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
258	Cu(II)	Ja97	HWIR	Soil E	Netherlands	529	2.72	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
251	Cu(II)	Ge82	Listing	sandy loam	Netherlands	500	2.7	7.8	2.25									

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
259	Cu(II)	Ja97	HWIR	Soil F	Netherlands	452	2.66	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
257	Cu(II)	Ja97	HWIR	Soil D	Netherlands	322	2.51	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
252	Cu(II)	Ge82	Listing	sand	Netherlands	155	2.19	4.8	1.75									
265	Cu(II)	Ja97	HWIR	Soil M	Netherlands	135	2.13	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
253	Cu(II)	Ja97	HWIR	Soil L	Netherlands	109	2.04	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
255	Cu(II)	Ja97	HWIR	Soil B	Netherlands	92	1.96	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
266	Cu(II)	Ja97	HWIR	Soil N	Netherlands	88	1.94	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
264	Cu(II)	Ja97	HWIR	Soil K	Netherlands	67	1.83	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
262	Cu(II)	Ja97	HWIR	Soil I	Netherlands	38	1.58	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
254	Cu(II)	Ja97	HWIR	Soil A	Netherlands	35	1.54	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
261	Cu(II)	Ja97	HWIR	Soil H	Netherlands	25	1.4	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
275	Hg(II)	Ly97	HWIR	soil (from Aa91)		10526	4.02											
277	Hg(II)	Ly97	HWIR	soil (from Le94)		8328	3.92											
276	Hg(II)	Ly97	HWIR	soil (from Le95)		8000	3.9											
279	Hg(II)	Ge82	Listing	sandy loam	Netherlands	7600	3.88	7.8	2.25									
280	Hg(II)	Ge82	Listing	sand	Netherlands	4500	3.65	4.8	1.75									
278	Hg(II)	Sc97	HWIR	iron-humus podozol	Norway	1924	3.28	4.5	2.3									
281	Hg(II)	Bi91	Listing	Rhine aquifer sand	France	2.2	0.34									0.1		
273	Hg(II)	Mac93	Listing	coastal plain	NJ	0.78	-0.11	4.5	1.55									
274	Hg(II)	Mac93	Listing	Bridgeton Fmt./Cohansey Sand	NJ	0.22	-0.66	4.5										

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
288	Mn	Mi82	Listing	Soil 5: heavy clay	Finland	4100	3.61	8									25	meq/100g
284	Mn	Mi82	Listing	Soil 1: heavy clay	Finland	1000	3	8.2									26	meq/100g
289	Mn	Mi82	Listing	Soil 6: silty clay	Finland	430	2.63	7									17	meq/100g
282	Mn	Ya95	Listing	paddy and upland agricultural soils	Japan	271	2.43	5.85									107	mmol/kg
292	Mn	Mi82	Listing	Soil 9: sandy till	Finland	160	2.2	6.8										meq/100g
285	Mn	Mi82	Listing	Soil 10: sandy till	Finland	130	2.11	6.2										meq/100g
286	Mn	Mi82	Listing	Soil 3: heavy clay	Finland	96	1.98	8.4									21	meq/100g
290	Mn	Mi82	Listing	Soil 7: sandy till	Finland	86	1.93	6.4									2.8	meq/100g
291	Mn	Mi82	Listing	Soil 8: sandy till	Finland	49	1.69	6.4									3.2	meq/100g
293	Mn	Sh89	Listing	69 different soils	SW Ontario	44	1.64	6.7	2.05							14		
283	Mn	St86	Listing	Shelocta silt loam	TN	36	1.56											
287	Mn	Mi82	Listing	Soil 4: heavy clay	Finland	34	1.53	8.3									5.7	meq/100g
297	Mo(VI)	Ge82	Listing	sand	Netherlands	162.5	2.21	4.8	1.75									
294	Mo(VI)	Is93	HWIR	two soil horizons		148	2.17	5.3	0.34			1.09	wt%					
295	Mo(VI)	Sh91a	HWIR	sandy soil	Canada	10.6	1.02	5.7	0.313			4646	mg/kg					

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
298	Mo(VI)	St95	Listing	sand/gravel alluvium	Cape Cod, MA	6.7	0.83	5.7		0.31	mg/L							
296	Mo(VI)	Ge82	Listing	sandy loam	Netherlands	2.75	0.44	7.8	2.25									
302	Ni(II)	Ch96	Listing	Gunderup 2 sand	Denmark	7250	3.86	8.75	0.292							0		
335	Ni(II)	Ja97	HWIR	Soil R	Netherlands	5749	3.76	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
338	Ni(II)	Ba92	Listing	London clay	England	4750	3.68			6	mg/L							
301	Ni(II)	Ch96	Listing	Gunderup 1 sand	Denmark	4510	3.65	8.87	0.032							1		
313	Ni(II)	Ch96	Listing	Allerod 1 sand	Denmark	4370	3.64	8.83	0.133							2		
336	Ni(II)	Ja97	HWIR	Soil S	Netherlands	4113	3.61	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
326	Ni(II)	Ja97	HWIR	Soil G	Netherlands	3151	3.5	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
308	Ni(II)	Ch96	Listing	Vasby sand	Denmark	2750	3.44	8.87	0.113							1		
337	Ni(II)	Ja97	HWIR	Soil T	Netherlands	2310	3.36	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
334	Ni(II)	Ja97	HWIR	Soil Q	Netherlands	2163	3.34	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
333	Ni(II)	Ja97	HWIR	Soil P	Netherlands	1857	3.27	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
324	Ni(II)	Ja97	HWIR	Soil E	Netherlands	1843	3.27	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
321	Ni(II)	Ja97	HWIR	Soil B	Netherlands	1660	3.22	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
314	Ni(II)	Ch96	Listing	Allerod 2 sand	Denmark	1510	3.18	8.47	0.083							0		
305	Ni(II)	Ch96	Listing	Tirstrup 1 sand	Denmark	1430	3.16	8.51	0.306							3		
325	Ni(II)	Ja97	HWIR	Soil F	Netherlands	1285	3.11	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
322	Ni(II)	Ja97	HWIR	Soil C	Netherlands	1255	3.1	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
319	Ni(II)	Ja97	HWIR	Soil L	Netherlands	1088	3.04	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
332	Ni(II)	Ja97	HWIR	Soil O	Netherlands	744	2.87	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
300	Ni(II)	Ch96	Listing	Finderup 2 sand	Denmark	450	2.65	7.96	0.108							0		
307	Ni(II)	Ch96	Listing	Tylstrup sand	Denmark	440	2.64	8.01	0.167							4		
311	Ni(II)	Ch96	Listing	Vorbasse 2 sand	Denmark	420	2.62	8.46	0.01							0		
331	Ni(II)	Ja97	HWIR	Soil M	Netherlands	376	2.58	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
317	Ni(II)	Ge82	Listing	sandy loam	Netherlands	350	2.54	7.8	2.25									
306	Ni(II)	Ch96	Listing	Tirstrup 2 sand	Denmark	310	2.49	8.41	0.046							2		
320	Ni(II)	Ja97	HWIR	Soil A	Netherlands	292	2.47	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
303	Ni(II)	Ch96	Listing	Herborg sand	Denmark	250	2.4	7.85	0.213							0		
323	Ni(II)	Ja97	HWIR	Soil D	Netherlands	243	2.39	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
329	Ni(II)	Ja97	HWIR	Soil J	Netherlands	236	2.37	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
330	Ni(II)	Ja97	HWIR	Soil K	Netherlands	185	2.27	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
328	Ni(II)	Ja97	HWIR	Soil I	Netherlands	130	2.11	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
327	Ni(II)	Ja97	HWIR	Soil H	Netherlands	115	2.06	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
318	Ni(II)	Ge82	Listing	sand	Netherlands	49.5	1.69	4.8	1.75									
312	Ni(II)	Ch96	Listing	Vorbasse 3 sand	Denmark	40	1.6	5.83	0.072							1		
310	Ni(II)	Ch96	Listing	Vorbasse 1 sand	Denmark	40	1.6	6.77	0.011							1		
315	Ni(II)	Ch96	Listing	Borris sand	Denmark	24	1.38	5.86	0.032							0		
299	Ni(II)	Ch96	Listing	Finderup 1 sand	Denmark	18	1.26	6.19	0.007							1		
309	Ni(II)	Ch96	Listing	Vejen sand	Denmark	12	1.08	5.66	0.034							1		
316	Ni(II)	Ch96	Listing	Brande sand	Denmark	7	0.85	5.28	0.028							1		
304	Ni(II)	Ch96	Listing	Rabis Baek sand	Denmark	3	0.48	4.91	0.482							1		
371	Pb(II)	Ja97	HWIR	Soil T	Netherlands	67856	4.83	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
360	Pb(II)	Ja97	HWIR	Soil G	Netherlands	60311	4.78	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
345	Pb(II)	Sh91b	HWIR	loam	Canada	60000	4.78	7										
343	Pb(II)	Sh91b	HWIR	clay loam	Canada	60000	4.78	7										
349	Pb(II)	Sh89b	HWIR	fine sandy loam	Canada	59000	4.77	7.4								11		
373	Pb(II)	Rh92	OAR	sand	Hanford, WA	46000	4.66	8.35				0.41	wt%			0.06	5.27	meq/100g
369	Pb(II)	Ja97	HWIR	Soil R	Netherlands	45502	4.66	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
357	Pb(II)	Ja97	HWIR	Soil D	Netherlands	42250	4.63	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
367	Pb(II)	Ja97	HWIR	Soil P	Netherlands	37379	4.57	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
366	Pb(II)	Ja97	HWIR	Soil O	Netherlands	36930	4.57	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
356	Pb(II)	Ja97	HWIR	Soil C	Netherlands	34727	4.54	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
346	Pb(II)	Sh91b	HWIR	sedge peat	Canada	30000	4.48	5.5										
368	Pb(II)	Ja97	HWIR	Soil Q	Netherlands	27722	4.44	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
353	Pb(II)	Ja97	HWIR	Soil L	Netherlands	22944	4.36	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
344	Pb(II)	Sh91b	HWIR	gleysol loam	Canada	21000	4.32	7.3										
370	Pb(II)	Ja97	HWIR	Soil S	Netherlands	16973	4.23	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
359	Pb(II)	Ja97	HWIR	Soil F	Netherlands	12514	4.1	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
347	Pb(II)	Sh91b	HWIR	spaghnum peat	Canada	9000	3.95	4.8										
363	Pb(II)	Ja97	HWIR	Soil J	Netherlands	5923	3.77	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
358	Pb(II)	Ja97	HWIR	Soil E	Netherlands	5310	3.73	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
351	Pb(II)	Ge82	Listing	sandy loam	Netherlands	4250	3.63	7.8	2.25									
377	Pb(II)	Ha81	OAR	Split Rock Fmt.	WY	4000	3.6	7										
365	Pb(II)	Ja97	HWIR	Soil M	Netherlands	3550	3.55	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
354	Pb(II)	Ja97	HWIR	Soil A	Netherlands	3428	3.54	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
355	Pb(II)	Ja97	HWIR	Soil B	Netherlands	2637	3.42	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
376	Pb(II)	Ha81	OAR	Split Rock Fmt.	WY	1500	3.18	5.75										
361	Pb(II)	Ja97	HWIR	Soil H	Netherlands	1326	3.12	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
362	Pb(II)	Ja97	HWIR	Soil I	Netherlands	1159	3.06	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
364	Pb(II)	Ja97	HWIR	Soil K	Netherlands	916	2.96	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
352	Pb(II)	Ge82	Listing	sand	Netherlands	750	2.88	4.8	1.75									
341	Pb(II)	Me94	HWIR	acidic soil	England	126	2.1	4.1	7.9									
375	Pb(II)	Ha81	OAR	Split Rock Fmt.	WY	100	2	4.5										
342	Pb(II)	Me94	HWIR	acidic soil	England	96	1.98	3.4	13.3									
339	Pb(II)	Me94	HWIR	acidic soil	England	93	1.97	4.6	10.5									
372	Pb(II)	Fu96	Listing	sandy glacial outwash	Cape Cod, MA	24.4	1.39	5.3										
374	Pb(II)	Ha81	OAR	Split Rock Fmt.	WY	20	1.3	2										
348	Pb(II)	Sh91b	HWIR	Brunisol sand	Canada	19.8	1.3	4.9										
350	Pb(II)	Sh89b	HWIR	medium sand	Canada	19	1.28	4.9								2		
340	Pb(II)	Me94	HWIR	acidic soil	England	14	1.15	4	5.7									
378	Sb(III)	Ge82	Listing	sandy loam	Netherlands	14	1.15	7.8	2.25									
379	Sb(III)	Ge82	Listing	sand	Netherlands	11	1.04	4.8	1.75									
387	Se(IV)	Fi91	HWIR	Soil CS	CA	46.7	1.67	8.3										
389	Se(IV)	Sa94	HWIR	Mukaiyama	Japan	35	1.54	5	13.44			1.23	wt%					
382	Se(IV)	Ne87	HWIR	Los Banos	CA	34.5	1.54	5.5	1.02			0.09	wt%					
385	Se(IV)	Ch89	HWIR	Ronhave soil	Denmark	31	1.5	6.5	1.21			0.608	wt%					
386	Se(IV)	Fi91	HWIR	Site 3 soil	CA	30	1.48	8.3										
392	Se(IV)	Ge82	Listing	sandy loam	Netherlands	27.5	1.44	7.8	2.25									

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlO x	AlOx units	Clay_ wt%	CEC	CEC units
393	Se(IV)	Ge82	Listing	sand	Netherlands	26	1.41	4.8	1.75									
388	Se(IV)	Ch89	HWIR	Studsgaard	Denmark	23.5	1.37	6.6	2.37			0.686	wt%					
381	Se(IV)	Ne87	HWIR	Ciervo	CA	18.9	1.28	4.2	0.69			0.11	wt%					
390	Se(IV)	Sa94	HWIR	Tanashi	Japan	16.5	1.22	5	8.25			1.75	wt%					
383	Se(IV)	Ne87	HWIR	Pan Hill	CA	10.7	1.03	5.9	0.53			0.1	wt%					
391	Se(IV)	Fi90	Listing	Ciervo silty clay series	CA	10.5	1.02	8.3										
384	Se(IV)	Ne87	HWIR	Panoche	CA	9.2	0.97	6	0.73			0.06	wt%					
380	Se(IV)	Ne87	HWIR	Altamont	CA	2.17	0.34	8.1	2.9									
394	Sn	Ge82	Listing	sandy loam	Netherlands	7750	3.89	7.8	2.25									
395	Sn	Ge82	Listing	sand	Netherlands	2150	3.33	4.8	1.75									
396	V(IV)	Ge82	Listing	sandy loam	Netherlands	330	2.52	7.8	2.25									
397	V(IV)	Ge82	Listing	sand	Netherlands	75	1.88	4.8	1.75									
427	Zn(II)	Mi82	Listing	Soil 5: heavy clay	Finland	28000	4.45	8									25	meq/100g
422	Zn(II)	Mi82	Listing	Soil 1: heavy clay	Finland	15000	4.18	8.2									26	meq/100g
424	Zn(II)	Mi82	Listing	Soil 2: heavy clay	Finland	14000	4.15	8.2										meq/100g
428	Zn(II)	Mi82	Listing	Soil 6: silty clay	Finland	9100	3.96	7									17	meq/100g
420	Zn(II)	Ja97	HWIR	Soil S	Netherlands	6762	3.83	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
409	Zn(II)	Ja97	HWIR	Soil G	Netherlands	6226	3.79	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
437	Zn(II)	Le98	Listing	Wan-li loam	Taiwan	5667	3.75	6.51	1.9							11.5	1	meq/100g
425	Zn(II)	Mi82	Listing	Soil 3: heavy clay	Finland	5600	3.75	8.4									21	meq/100g

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
421	Zn(II)	Ja97	HWIR	Soil T	Netherlands	5472	3.74	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
419	Zn(II)	Ja97	HWIR	Soil R	Netherlands	5112	3.71	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
429	Zn(II)	Mi82	Listing	Soil 7: sandy till	Finland	5100	3.71	6.4									2.8	meq/100g
430	Zn(II)	Mi82	Listing	Soil 8: sandy till	Finland	5000	3.7	6.4									3.2	meq/100g
417	Zn(II)	Ja97	HWIR	Soil P	Netherlands	3698	3.57	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
423	Zn(II)	Mi82	Listing	Soil 10: sandy till	Finland	3200	3.51	6.2										meq/100g
426	Zn(II)	Mi82	Listing	Soil 4: heavy clay	Finland	3000	3.48	8.3									5.7	meq/100g
406	Zn(II)	Ja97	HWIR	Soil D	Netherlands	2800	3.45	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
431	Zn(II)	Mi82	Listing	Soil 9: sandy till	Finland	2700	3.43	6.8										meq/100g
407	Zn(II)	Ja97	HWIR	Soil E	Netherlands	2438	3.39	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
405	Zn(II)	Ja97	HWIR	Soil C	Netherlands	2245	3.35	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
400	Zn(II)	Ge82	Listing	sandy loam	Netherlands	2050	3.31	7.8	2.25									
433	Zn(II)	Le98	Listing	Hu-shan farm sand	Taiwan	1989	3.3	6.89	0.55							6.5	7.3	meq/100g
399	Zn(II)	Ya95	Listing	paddy and upland agricultural soils	Japan	1756	3.24	5.85									107	mmol/kg
408	Zn(II)	Ja97	HWIR	Soil F	Netherlands	1299	3.11	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
402	Zn(II)	Ja97	HWIR	Soil L	Netherlands	1294	3.11	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
418	Zn(II)	Ja97	HWIR	Soil Q	Netherlands	1278	3.11	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
435	Zn(II)	Le98	Listing	Kuei-jen loam	Taiwan	995	3	6.38	0.45							9	8.1	meq/100g
404	Zn(II)	Ja97	HWIR	Soil B	Netherlands	604	2.78	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		

(continued)

Table H-17. (continued)

ID	Species	Ref. Index	Study	Media Type	Location	Kd L/kg	LogKd	pH	POC_ wt%	DOC	DOC units	FeOx	FeOx units	AlOx	AlOx units	Clay_ wt%	CEC	CEC units
416	Zn(II)	Ja97	HWIR	Soil O	Netherlands	422	2.63	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
412	Zn(II)	Ja97	HWIR	Soil J	Netherlands	154	2.19	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
403	Zn(II)	Ja97	HWIR	Soil A	Netherlands	73	1.86	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
436	Zn(II)	Le98	Listing	Niu-chou-pu sandy loam	Taiwan	72.5	1.86	4.81	0.15							12	8.5	meq/100g
401	Zn(II)	Ge82	Listing	sand	Netherlands	55.5	1.74	4.8	1.75									
398	Zn(II)	Sc88	HWIR	forest soil	Bavaria	41	1.61	3.7								3		
411	Zn(II)	Ja97	HWIR	Soil I	Netherlands	41	1.61	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
414	Zn(II)	Ja97	HWIR	Soil N	Netherlands	38	1.58	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
413	Zn(II)	Ja97	HWIR	Soil K	Netherlands	34	1.53	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
434	Zn(II)	Le98	Listing	Hu-tou-pi sandy loam	Taiwan	33.8	1.53	3.96	0.4							10	8.1	meq/100g
410	Zn(II)	Ja97	HWIR	Soil H	Netherlands	23	1.36	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
415	Zn(II)	Ja97	HWIR	Soil M	Netherlands	6	0.78	6.4	2.8	5.4	mmol/L	88.6	mmol/kg	26.1	mmol/kg	6.5		
432	Zn(II)	Fu96	Listing	sandy glacial outwash	Cape Cod, MA	2.7	0.43	5.3										

Table H-18. Measured K^d Values: Sol and Aquifer Material Characteristics

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
9	Ag	Listing	Ba92	aquifer	6700	3.83	8	groundwater	batch (L:S not specified)	mean of three 0.45um-filtered replicates (Table 6); Total_Ag=3e-07 M; mean pH of replicates
3	Ag	HWIR	Jo86	soil	3323	3.52	5.8			contaminated soil from silver mining area
8	Ag	Listing	Ba92	aquifer	2570	3.41	7.8	synthesized groundwater	batch (L:S not specified)	mean of three 0.45um-filtered replicates (Table 6); Total_Ag=2e-06 M; mean pH of replicates
5	Ag	Listing	Ge82	soil	1250	3.1	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
4	Ag	HWIR	Sz95	soil	1200	3.08				"eyeballed" from graph of Kd vs pH; plotted Kd's varied little with pH range 4 to 8
6	Ag	Listing	Ge82	soil	650	2.81	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
7	Ag	HWIR	Jo86	soil	390	2.59	4.2			uncontaminated soil from silver mining area
1	Ag	HWIR	Jo86	soil	137	2.14	6			contaminated soil from silver mining area
2	Ag	HWIR	Jo86	soil	26.8	1.43	5.9			contaminated soil from silver mining area
39	As(V)	HWIR	Ja97	soil	20412	4.31	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
42	As(V)	HWIR	Ja97	soil	9745	3.99	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
27	As(V)	HWIR	Ja97	soil	7243	3.86	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
31	As(V)	HWIR	Ja97	soil	6649	3.82	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
26	As(V)	HWIR	Ja97	soil	6075	3.78	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
34	As(V)	HWIR	Ja97	soil	5313	3.73	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
28	As(V)	HWIR	Ja97	soil	3829	3.58	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
30	As(V)	HWIR	Ja97	soil	3794	3.58	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
41	As(V)	HWIR	Ja97	soil	3127	3.5	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
29	As(V)	HWIR	Ja97	soil	2905	3.46	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
43	As(V)	HWIR	Ja97	soil	2521	3.4	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
44	As(V)	HWIR	Ja97	soil	2289	3.36	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
37	As(V)	HWIR	Ja97	soil	2109	3.32	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
40	As(V)	HWIR	Ja97	soil	2015	3.3	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
36	As(V)	HWIR	Ja97	soil	1502	3.18	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
25	As(V)	HWIR	Ja97	soil	1362	3.13	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
38	As(V)	HWIR	Ja97	soil	804	2.91	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
10	As	Listing	On96	aquifer	225	2.35		water (NOS)	batch (23:5)	calculated from %sorbed and solid:liquid ratio for total As of 6.6 mg/L; more sorption (implying higher Kd) was observed for experiments with lower total As, but values could not be determined
35	As(V)	HWIR	Ja97	soil	158	2.2	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
23	As(V)	Listing	Ge82	soil	125	2.1	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
12	As	Listing	Ku97a	soil	120	2.08	11	groundwater	column desorption	selected long term experiment & stabilized value (25 void volumes); note alkaline pH
33	As(V)	HWIR	Ja97	soil	97	1.99	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
32	As(V)	HWIR	Ja97	soil	90	1.95	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
22	As(V)	HWIR	Is93	soil	67	1.83	5.3			calculated from sorbed conc data plotted against solution conc for two soil horizons of one soil; mean Kd, pH, POC values
24	As(V)	Listing	Ge82	soil	45	1.65	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
18	As	Listing	Jo99	soil	33.2	1.52	8	0.01 M KCl	batch (20 mL:10 g)	from Table 1 (p. 1317); [Kd = 0.015 (AOE Fe) + 0.038 (AOE Mn) - 0.62 (Olsen P) + 3.3]; mean soil properties
14	As	Listing	DOE93	aquifer	19.4	1.29	7.2	groundwater	batch (L:S varies)	obtained from Freundlich isotherm parameters (Fig. 4.4) using 1 mg/l for dissolved conc; range of solid:liquid ratios (1g:1mL to 1g:40mL) were used to generate Freundlich isotherm points
16	As	Listing	Jo99	soil	18.8	1.27	8	0.01 M KCl	batch (20 mL:10 g)	median of two reported values (Table 1, p. 1317); [Kd = 0.015 (AOE Fe) + 0.038 (AOE Mn) - 0.62 (Olsen P) + 3.3]; mean soil properties
19	As	Listing	Jo99	soil	13	1.11	8	0.01 M KCl	batch (20 mL:10 g)	from Table 1 (p. 1317); [Kd = 0.015 (AOE Fe) + 0.038 (AOE Mn) - 0.62 (Olsen P) + 3.3];mean soil properties

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
21	As(III)	HWIR	Is93	soil	12	1.08	5.3			calculated from sorbed conc data plotted against solution conc for two soil horizons of one soil; mean Kd, pH, POC values
15	As	Listing	Jo99	soil	10.4	1.02	8	0.01 M KCl	batch (20 mL:10 g)	median of two reported values (Table 1, p. 1317); [Kd = 0.015 (AOE Fe) + 0.038 (AOE Mn) - 0.62 (Olsen P) + 3.3]; mean soil properties
13	As	Listing	Ku97b	aquifer	2.97	0.47	7	groundwater	column adsorption	average values for two columns from same aquifer (different depths)
17	As	Listing	Ca98	aquifer	1.86	0.27	7	0.1 M & 0.01 M NaNO3	batch (L:S varies)	from Figure 5 (p. 255); no units reported, but value of retardation factor in Table 3 is consistent with L/kg.
20	As(III)	HWIR	Is93	soil	1.13	0.05	5.3			calculated from sorbed conc data plotted against solution conc for two soil horizons of one soil; mean Kd, pH, POC values
11	As	Listing	Za92	aquifer	0.005	-2.3	7.4	groundwater	field study	Kd estimated from Rf, assume effective posity = total porosity = 0.26;assumed bulk density = 2.0, As2O3 tracer; mean Rf, 10 and 20 m
52	B	Listing	El82	soil	3.99	0.6	7.57	0.01 M CaCl2	batch (20 mL:20 g)	"adsorption" value from Table 4, K for Freundlich, assumes C = 1 ppm
46	B	Listing	Go91	soil	3.92	0.59		0.1 M NaCl	batch (25 mL:5 g)	avg. of two "untreated" values from Table 1 for Freundlich "nonlinear" case, assumes C = 1ppm in Freundlich eq.; average value multiplied by 100 to get L/kg
50	B	Listing	Sa97	soil	3.58	0.55	8.15	0.03 M KNO3	batch (20 mL:5 g)	Freundlich adsorption constants (did not use desorption constants)
58	B	Listing	El82	soil	3.33	0.52	7.54	0.01 M CaCl2	batch (20 mL:20 g)	"adsorption" value from Table 4, K for Freundlich, assumes C = 1 ppm
54	B	Listing	El82	soil	2.53	0.4	7.62	0.01 M CaCl2	batch (20 mL:20 g)	"adsorption" value from Table 4, K for Freundlich, assumes C = 1 ppm
49	B	Listing	Sa97	soil	2.34	0.37	7.15	0.03 M KNO3	batch (20 mL:5 g)	Freundlich adsorption constants (did not use desorption constants)
53	B	Listing	El82	soil	2.16	0.33	7.42	0.01 M CaCl2	batch (20 mL:20 g)	"adsorption" value from Table 4, K for Freundlich, assumes C = 1 ppm

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
45	B	Listing	El82	soil	1.93	0.29	6.02	0.01 M CaCl2	batch (20 mL:20 g)	"adsorption" value from Table 4, K for Freundlich, assumes C = 1 ppm
48	B	Listing	Sa97	soil	1.93	0.29	5	0.03 M KNO3	batch (20 mL:5 g)	Freundlich adsorption constants (did not use desorption constants)
71	B	Listing	Mo93	soil	1.53	0.18		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
63	B	Listing	Mo93	soil	1.52	0.18		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
67	B	Listing	Mo93	soil	1.4	0.15		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
65	B	Listing	Mo93	soil	1.37	0.14		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
47	B	Listing	Sa97	soil	1.35	0.13	7.52	0.03 M KNO3	batch (20 mL:5 g)	Freundlich adsorption constants (did not use desorption constants)
68	B	Listing	Mo93	soil	1.29	0.11		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
62	B	Listing	Mo93	soil	1.24	0.09		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
70	B	Listing	Mo93	soil	1.18	0.07		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
66	B	Listing	Mo93	soil	1.15	0.06		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
74	B	Listing	Mo93	soil	1.14	0.06		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
75	B	Listing	Mo93	soil	1.08	0.03		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
76	B	Listing	Mo93	soil	0.97	-0.01		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
77	B	Listing	Mo93	soil	0.94	-0.03		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
72	B	Listing	Mo93	soil	0.93	-0.03		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
64	B	Listing	Mo93	soil	0.89	-0.05		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
73	B	Listing	Mo93	soil	0.86	-0.07		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
78	B	Listing	Ye95	soil	0.62	-0.21	7.5	0.005 M CaCl2	batch (20 mL:5 g)	from Fig 1 with no added composted OM, pH 7.5 (closest to natural pH of 7.8)
56	B	Listing	El82	soil	0.421	-0.38	7.89	0.01 M CaCl2	batch (20 mL:20 g)	"adsorption" value from Table 4, K for Freundlich, assumes C = 1 ppm
55	B	Listing	El82	soil	0.409	-0.39	6.02	0.01 M CaCl2	batch (20 mL:20 g)	"adsorption" value from Table 4, K for Freundlich, assumes C = 1 ppm
60	B	Listing	Go91	soil	0.35	-0.46		0.1 M NaCl	batch (25 mL:5 g)	avg. of two "untreated" values from Table 1 for Freundlich "nonlinear" case, assumes C = 1ppm in Freundlich eq.; average value multiplied by 100 to get L/kg
69	B	Listing	Mo93	soil	0.32	-0.49		0.03 M KNO3	batch (20 mL:10 g)	recalculated from "Freundlich" isotherm (Table 2) assuming C = 1 ppm; soil properties given as ranges
57	B	Listing	El82	soil	0.162	-0.79	7.82	0.01 M CaCl2	batch (20 mL:20 g)	"adsorption" value from Table 4, K for Freundlich, assumes C = 1 ppm
51	B	Listing	El82	soil	0.125	-0.9	8	0.01 M CaCl2	batch (20 mL:20 g)	"adsorption" value from Table 4, K for Freundlich, assumes C = 1 ppm
59	B	Listing	El82	soil	0.087	-1.06	7.03	0.01 M CaCl2	batch (20 mL:20 g)	"adsorption" value from Table 4, K for Freundlich, assumes C = 1 ppm

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
61	B	Listing	Br97	aquifer	0.06	-1.22	7.57	groundwater	field tracer	median of calculated values based on in situ observations from 5 sampling points vertically, radially disposed.
79	Ba(II)	Listing	Ge82	soil	1355	3.13	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
80	Ba(II)	Listing	Ge82	soil	42.5	1.63	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
81	Be(II)	Listing	Ge82	soil	10000	4	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
82	Be(II)	Listing	Ge82	soil	372.5	2.57	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
167	Cd(II)	HWIR	Ja97	soil	18263	4.26	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
166	Cd(II)	HWIR	Ja97	soil	6446	3.81	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
165	Cd(II)	HWIR	Ja97	soil	6298	3.8	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
153	Cd(II)	HWIR	Ja97	soil	5828	3.77	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
155	Cd(II)	HWIR	Ja97	soil	5049	3.7	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
163	Cd(II)	HWIR	Ja97	soil	4653	3.67	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
147	Cd(II)	OAR	De91	soil	4360	3.64	8	groundwater (carbonate)	NA	groundwater pH
156	Cd(II)	HWIR	Ja97	soil	3549	3.55	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
173	Cd(II)	HWIR	Ku91	soil	2600	3.41	6			
174	Cd(II)	HWIR	Ku91	soil	2200	3.34	6			
178	Cd(II)	HWIR	Ku91	soil	2175	3.34	6.5			
145	Cd(II)	Listing	Ge82	soil	2000	3.3	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
134	Cd(II)	Listing	Ch96	aquifer	1770	3.25	8.83	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
183	Cd(II)	HWIR	Ch85	soil	1700	3.23	6.65	0.001 M CaCl2		

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
124	Cd(II)	Listing	Ch96	aquifer	1610	3.21	8.75	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
172	Cd(II)	Listing	Le98	soil	1595	3.2	6.51	0.01 N NaNO3	batch (100:1)	values at soil pH from Table 3 (Kd at other pH's also presented)
105	Cd(II)	HWIR	An88	soil	1386.8	3.14	7.3	0.001M CaCl2		Co = 0.7 to 12.6 ppb
154	Cd(II)	HWIR	Ja97	soil	1378	3.14	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
151	Cd(II)	HWIR	Ja97	soil	1078	3.03	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
123	Cd(II)	Listing	Ch96	aquifer	1010	3	8.87	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
148	Cd(II)	OAR	De91	soil	1000	3	8	groundwater (carbonate)	NA	groundwater pH
162	Cd(II)	HWIR	Ja97	soil	974	2.99	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
164	Cd(II)	HWIR	Ja97	soil	948	2.98	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
181	Cd(II)	HWIR	Ch85	soil	780	2.89	6.65	0.001 M CaCl2		
175	Cd(II)	HWIR	Ku91	soil	770	2.89	6			
104	Cd(II)	HWIR	An88	soil	769.1	2.89	6.9	0.001M CaCl2		Co = 0.7 to 12.6 ppb
119	Cd(II)	OAR	Bu89	soil	755.1	2.88	7.6	0.005 M CaNO3	NA	converted Freund. to Kd using 1ppm
152	Cd(II)	HWIR	Ja97	soil	755	2.88	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
122	Cd(II)	Listing	Ch96	aquifer	720	2.86	7.96	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
176	Cd(II)	HWIR	Ku91	soil	710	2.85	6			

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
127	Cd(II)	Listing	Ch96	aquifer	670	2.83	8.51	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
131	Cd(II)	Listing	Ch96	aquifer	660	2.82	8.46	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
128	Cd(II)	Listing	Ch96	aquifer	640	2.81	8.01	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
150	Cd(II)	HWIR	Ja97	soil	603	2.78	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
135	Cd(II)	Listing	Ch96	aquifer	560	2.75	8.47	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
159	Cd(II)	HWIR	Ja97	soil	532	2.73	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
125	Cd(II)	Listing	Ch96	aquifer	500	2.7	7.85	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
103	Cd(II)	HWIR	An88	soil	494.3	2.69	6.6	0.001M CaCl2		Co = 0.7 to 12.6 ppb
138	Cd(II)	OAR	Ma92	soil	488.4	2.69	6.8	0.01 M NaCl	NA	desorption (average of 2 measurements)
177	Cd(II)	HWIR	Ku91	soil	475	2.68	6			
168	Cd(II)	Listing	Le98	soil	461.8	2.66	6.89	0.01 N NaNO3	batch (100:1)	values at soil pH from Table 3 (Kd at other pH's also presented)
102	Cd(II)	HWIR	An88	soil	368.1	2.57	6.4	0.001M CaCl2		Co = 0.7 to 12.6 ppb
170	Cd(II)	Listing	Le98	soil	303.2	2.48	6.38	0.01 N NaNO3	batch (100:1)	values at soil pH from Table 3 (Kd at other pH's also presented)
179	Cd(II)	HWIR	Ku91	soil	300	2.48	5			
108	Cd(II)	OAR	Bu89	soil	288.4	2.46	5.7	0.005 M CaNO3	NA	converted Freund. to Kd using 1ppm

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
101	Cd(II)	HWIR	An88	soil	274.2	2.44	6.2	0.001M CaCl2		Co = 0.7 to 12.6 ppb
90	Cd(II)	OAR	Na78	soil	266.7	2.43	7.9	0.01 M NaCl	NA	calculated from Figure 1
142	Cd(II)	Listing	Za92	aquifer	255	2.41	7.4	groundwater	field study	Kd estimated from Rf, assume effective posity = total porosity = 0.26; assumed bulk density = 2.0, CdCl2 tracer; mean Rf, 10 and 20 m
182	Cd(II)	HWIR	Ch85	soil	250	2.4	5.5	0.001 M CaCl2		
184	Cd(II)	HWIR	Ch85	soil	225	2.35	5.5	0.001 M CaCl2		
100	Cd(II)	HWIR	An88	soil	204.2	2.31	6	0.001M CaCl2		Co = 0.7 to 12.6 ppb
146	Cd(II)	Listing	Ge82	soil	201.5	2.3	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
140	Cd(II)	HWIR	Al95	soil	200	2.3	5.12	0.01 N NaNO3	batch (100 mL:1 g)	adsoption study; Kd estimated from Kd-pH relation using natural system pH (5.12)
87	Cd(II)	OAR	Na78	soil	200	2.3	7.8	0.01 M NaCl	NA	calculated from Figure 1
110	Cd(II)	OAR	Bu89	soil	186.6	2.27	5.9	0.005 M CaNO3	NA	converted Freund. to Kd using 1ppm
91	Cd(II)	OAR	Na78	soil	181.8	2.26	7.6	0.01 M NaCl	NA	calculated from Figure 1
130	Cd(II)	Listing	Ch96	aquifer	180	2.26	6.77	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
180	Cd(II)	HWIR	Ku91	soil	175	2.24	4.5			
158	Cd(II)	HWIR	Ja97	soil	159	2.2	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
99	Cd(II)	HWIR	An88	soil	152.1	2.18	5.8	0.001M CaCl2		Co = 0.7 to 12.6 ppb
157	Cd(II)	HWIR	Ja97	soil	144	2.16	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
89	Cd(II)	OAR	Na78	soil	133.3	2.12	8.3	0.01 M NaCl	NA	calculated from Figure 1
98	Cd(II)	HWIR	An88	soil	113.2	2.05	5.6	0.001M CaCl2		Co = 0.7 to 12.6 ppb
160	Cd(II)	HWIR	Ja97	soil	102	2.01	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
114	Cd(II)	OAR	Bu89	soil	97.9	1.99	6.6	0.005 M CaNO3	NA	converted Freund. to Kd using 1ppm
133	Cd(II)	HWIR	Sc88	soil	97	1.99	3.7			data from a single forest soil; reported "mean" Kd; Kd reported to exhibit a log-normal distrib
112	Cd(II)	OAR	Bu89	soil	91.2	1.96	6	0.005 M CaNO3	NA	converted Freund. to Kd using 1ppm
118	Cd(II)	OAR	Ga80	soil	87.1	1.94	8.4	water	NA	converted Freund. to Kd using 1ppm
97	Cd(II)	HWIR	An88	soil	84.3	1.93	5.4	0.001M CaCl2		Co = 0.7 to 12.6 ppb
88	Cd(II)	OAR	Na78	soil	80	1.9	8.2	0.01 M NaCl	NA	calculated from Figure 1
83	Cd(II)	HWIR	Me94	soil	69	1.84	4.6			acidic soil polluted with mine waste in England
96	Cd(II)	HWIR	An88	soil	62.8	1.8	5.2	0.001M CaCl2		Co = 0.7 to 12.6 ppb
111	Cd(II)	OAR	Bu89	soil	52.7	1.72	3.9	0.005 M CaNO3	NA	converted Freund. to Kd using 1ppm
106	Cd(II)	OAR	Bu89	soil	52.5	1.72	4.8	0.005 M CaNO3	NA	converted Freund. to Kd using 1ppm
95	Cd(II)	HWIR	An88	soil	46.8	1.67	5	0.001M CaCl2		Co = 0.7 to 12.6 ppb
132	Cd(II)	Listing	Ch96	aquifer	40	1.6	5.83	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
149	Cd(II)	Listing	St86	soil	38	1.58		not specified	batc (L:S not specified)	selected two values for bulk soil under ambient conditions; did not use values for organic-rich root channel macropores; no units given, assumed L/kg.
115	Cd(II)	OAR	Ga80	soil	33.88	1.53	5.2	water	NA	converted Freund. to Kd using 1ppm
86	Cd(II)	HWIR	Me94	soil	32	1.51	3.4			acidic soil polluted with mine waste in England
94	Cd(II)	HWIR	An88	soil	30.1	1.48	4.7	0.001M CaCl2		Co = 0.7 to 12.6 ppb
113	Cd(II)	OAR	Bu89	soil	28.8	1.46	6.9	0.005 M CaNO3	NA	converted Freund. to Kd using 1ppm
92	Cd(II)	Listing	Vu98	aquifer	26.3	1.42	5.8	not specified	column	median value for the three fresh samples
143	Cd(II)	HWIR	Al95	soil	25	1.4	4.7	0.01 N NaNO3	batch (100 mL:1 g)	adsoption study; Kd measured at pH (4.7) closest to natural system pH (4.69)
171	Cd(II)	Listing	Le98	soil	23.9	1.38	4.81	0.01 N NaNO3	batch (100:1)	values at soil pH from Table 3 (Kd at other pH’s also presented)
169	Cd(II)	Listing	Le98	soil	22.1	1.34	3.96	0.01 N NaNO3	batch (100:1)	values at soil pH from Table 3 (Kd at other pH’s also presented)
161	Cd(II)	HWIR	Ja97	soil	21	1.32	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
107	Cd(II)	OAR	Ga80	soil	20.42	1.31	5.8	water	NA	converted Freund. to Kd using 1ppm
93	Cd(II)	HWIR	An88	soil	19.3	1.29	4.4	0.001M CaCl2		Co = 0.7 to 12.6 ppb
139	Cd(II)	Listing	Pa99	aquifer	16.82	1.23	7.3	tap water (domestic well)	batch-static (150 mL:1400 g)	Freundlich constant (p. 194, batch tests)
85	Cd(II)	HWIR	Me94	soil	15	1.18	4.1			acidic soil polluted with mine waste in England
120	Cd(II)	OAR	Bu89	soil	14.4	1.16	5.3	0.005 M CaNO3	NA	converted Freund. to Kd using 1ppm

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
121	Cd(II)	Listing	Ch96	aquifer	14	1.15	6.19	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
141	Cd(II)	HWIR	Al95	soil	14	1.15	5.22	0.01 N NaNO3	batch (100 mL:1 g)	adsoption study; Kd estimated from Kd-pH relation using natural system pH (5.22)
129	Cd(II)	Listing	Ch96	aquifer	14	1.15	5.66	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
109	Cd(II)	OAR	Bu89	soil	13.9	1.14	5.4	0.005 M CaNO3	NA	converted Freund. to Kd using 1ppm
84	Cd(II)	HWIR	Me94	soil	12	1.08	4			acidic soil polluted with mine waste in England
144	Cd(II)	HWIR	Al95	soil	12	1.08	4.8	0.01 N NaNO3	batch (100 mL:1 g)	adsoption study; Kd measured at pH (4.8) closest to natural system pH (4.74)
136	Cd(II)	Listing	Ch96	aquifer	11	1.04	5.86	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
117	Cd(II)	OAR	Ga80	soil	10.47	1.02	6	water	NA	converted Freund. to Kd using 1ppm
137	Cd(II)	Listing	Ch96	aquifer	6	0.78	5.28	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
116	Cd(II)	OAR	Bu89	soil	5.5	0.74	4.3	0.005 M CaNO3	NA	converted Freund. to Kd using 1ppm
126	Cd(II)	Listing	Ch96	aquifer	2	0.3	4.91	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.67pH - 2.74
197	Co(II)	Listing	Mi82	aquifer	14000	4.15	8	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
204	Co(II)	Listing	Ta94	soil	5450	3.74	7.5	groundwater	batch (10 mL:1 g)	median of 16 soil samples, calculated from data in Table 3; average pH (range: 7.07 - 8.00)
198	Co(II)	Listing	Mi82	aquifer	4500	3.65	7	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
187	Co(II)	HWIR	Ban92	soil	4120	3.61	8			0.05 kg/L soil solid concentration is low for a soil system; PCE observed above soil solid conc of 0.05 kg/L; single experiment seemed to show that the Kd would be halved at Cs = 0.1 kg/L
189	Co(II)	Listing	Ge82	soil	3700	3.57	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
192	Co(II)	Listing	Mi82	aquifer	2200	3.34	8.2	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
194	Co(II)	Listing	Mi82	aquifer	1800	3.26	8.2	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
188	Co(II)	Listing	Ya95	soil	1735	3.24	5.85	rainwater	batch (30 mL:3 g)	median value from Table III (36 soils)
203	Co(II)	Listing	Ba92	aquifer	1430	3.16		groundwater	batch (L:S not specified)	mean of three 0.45um filtered replicates for Total_Co=4e-10 M; pH not specified; used Table 7 entries w/o added DOC.
195	Co(II)	Listing	Mi82	aquifer	990	3	8.4	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
193	Co(II)	Listing	Mi82	aquifer	880	2.94	6.2	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
196	Co(II)	Listing	Mi82	aquifer	410	2.61	8.3	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
201	Co(II)	Listing	Mi82	aquifer	400	2.6	6.8	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
202	Co(II)	Listing	Ha88	aquifer	232	2.37	7.3	groundwater	batch (9 mL:1 g)	avg. of two values from Table 4 for natural ground water.
199	Co(II)	Listing	Mi82	aquifer	160	2.2	6.4	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
200	Co(II)	Listing	Mi82	aquifer	140	2.15	6.4	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
185	Co(II)	HWIR	Ra96	soil	136	2.13	8.5			soil: 15% sand, 49% silt, 36% clay
191	Co(II)	HWIR	Ra96	soil	120	2.08	6.3			soil: 50% sand, 39% silt, 11% clay

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
186	Co(II)	HWIR	Sc88	soil	41	1.61	3.7			data from a single forest soil; reported "mean" Kd; Kd reported to exhibit a log-normal distrib
190	Co(II)	Listing	Ge82	soil	19	1.28	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
228	Cr(III)	HWIR	Ja97	soil	24217	4.38	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
209	Cr(III)	HWIR	Ha96b	soil	20833	4.32	6.2			
219	Cr(III)	HWIR	Ja97	soil	20665	4.32	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
226	Cr(III)	HWIR	Ja97	soil	19796	4.3	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
214	Cr(III)	HWIR	Ja97	soil	11992	4.08	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
227	Cr(III)	HWIR	Ja97	soil	11063	4.04	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
229	Cr(III)	HWIR	Ja97	soil	9519	3.98	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
230	Cr(III)	HWIR	Ja97	soil	9159	3.96	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
225	Cr(III)	HWIR	Ja97	soil	8906	3.95	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
215	Cr(III)	HWIR	Ja97	soil	8116	3.91	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
216	Cr(III)	HWIR	Ja97	soil	7933	3.9	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
218	Cr(III)	HWIR	Ja97	soil	6746	3.83	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
217	Cr(III)	HWIR	Ja97	soil	5977	3.78	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
208	Cr(III)	HWIR	Ha96b	soil	5075	3.71	6.52			glacially derived Zahl loam
212	Cr(III)	HWIR	Ja97	soil	4711	3.67	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
222	Cr(III)	HWIR	Ja97	soil	4219	3.63	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
220	Cr(III)	HWIR	Ja97	soil	3799	3.58	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
213	Cr(III)	HWIR	Ja97	soil	2747	3.44	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
221	Cr(III)	HWIR	Ja97	soil	2418	3.38	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
224	Cr(III)	HWIR	Ja97	soil	2364	3.37	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
206	Cr(III)	HWIR	Sh91a	soil	711	2.85	5.7			4-year study of a sandy soil originally spiked with Cr(III); the paper mentioned an associated "a" value as in the exponent for
207	Cr(III)	HWIR	Ha96b	soil	536	2.73	4.03			high clay lens in a soil taken near a river
223	Cr(III)	HWIR	Ja97	soil	524	2.72	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
211	Cr(III)	Listing	Ge82	soil	360	2.56	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
210	Cr(III)	Listing	Ge82	soil	25	1.4	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
238	Cr(VI)	OAR	Wo83	soil	1729	3.24	8.2	NA	NA	OAR (Table E-1)
244	Cr(VI)	OAR	Ra88	soil	1585	3.2	4.45	0.1 NaNO3	NA	value measured closest to soil pH (4.38); Cr: 1000000 M
234	Cr(VI)	OAR	Wo83	soil	1372	3.14	7.2	NA	NA	depth-average of 3 layers, assuming equal thickness; (OAR, Table E-1)
248	Cr(VI)	OAR	Sh87	soil	1000	3		NA	NA	OAR (Table E.1); little information provided
245	Cr(VI)	OAR	Ra88	soil	288	2.46	5.46	0.1 NaNO3	NA	value measured closest to soil pH (5.33); Cr: 1000000 M
250	Cr(VI)	OAR	Ra85	soil	110	2.04		NA	NA	tabulated data; little background information provided
249	Cr(VI)	OAR	Sh87	soil	100	2		NA	NA	OAR (Table E.1); little information provided
242	Cr(VI)	Listing	St85	aquifer	52	1.72	6.8	artficial groundwater	batch (15 mL:3 g)	upper end of Kd range (52 to 1.7 L/kg) from batch tests for a equilibrium CrO4-2 concentrations from 0.4 to 1400 umol/L; corresponding column test at 960 umol/L equil CrO4, gave Kd of 2.3 L/kg
241	Cr(VI)	OAR	Sh87b	soil	50	1.7	5.425	groundwater	column lysimeter	selected groundwater extractant (OAR, Table E-1, has leachate also); depth-weighted average assuming equal layer thickness
237	Cr(VI)	HWIR	Ha96b	soil	46.5	1.67	2.52			
235	Cr(VI)	HWIR	Ha96b	soil	26.9	1.43	2.29			high clay lens in a soil taken near a river
205	Cr(VI)	Listing	Ni94	aquifer	22	1.34	4.7	groundwater	field (in-situ measurements)	"apparent" partition coefficient estimated from mean %sorbed (99%), mean dry bulk density (1.6 g/cm3), and mean porosity (0.35) (p. 155); POC wt% value recorded was referred to as "organic content" in paper (may be wt% OM)

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
233	Cr(VI)	OAR	Se88	soil	10	1	5.1	0.005 M CaNO3	column	initial Cr 1 - 100 mg/L; OAR report gives range (9-10; Table E-1).
247	Cr(VI)	OAR	Ra85	soil	8	0.9		NA	NA	tabulated data; little background information provided
246	Cr(VI)	OAR	Ra88	soil	7	0.85	6.92	0.1 NaNO3	NA	value measured closest to soil pH (6.94); Cr: 1000000 M
232	Cr(VI)	OAR	Se88	soil	6	0.78	5.4	0.005 M CaNO3	column	initial Cr 1 - 100 mg/L; OAR report gives range (2-10; Table E-1).
240	Cr(VI)	Listing	St85	aquifer	5.3	0.72	6.8	artficial groundwater	batch (15 mL:3 g)	selected batch measurement closest to natural conditions
231	Cr(VI)	OAR	Se88	soil	2	0.3	6.4	0.005 M CaNO3	column	initial Cr 1 - 100 mg/L; OAR report gives range (1-3; Table E-1).
243	Cr(VI)	OAR	Ra88	soil	1	0	9.4	0.1 NaNO3	NA	value measured closest to soil pH (10.7); Cr: 1000000 M
236	Cr(VI)	HWIR	Ha96b	soil	0.5	-0.3	11.1			glacially derived Zahl loam
239	Cr(VI)	Listing	Me91	soil	0.2	-0.7		not specified	batch (L:S not specified)	report geared toward remediation options; Kd value on page 6; batch and column results agree
270	Cu(II)	HWIR	Ja97	soil	4318	3.64	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
267	Cu(II)	HWIR	Ja97	soil	1309	3.12	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
271	Cu(II)	HWIR	Ja97	soil	1253	3.1	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
260	Cu(II)	HWIR	Ja97	soil	1033	3.01	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
269	Cu(II)	HWIR	Ja97	soil	986	2.99	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
263	Cu(II)	HWIR	Ja97	soil	874	2.94	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
272	Cu(II)	HWIR	Ja97	soil	874	2.94	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
268	Cu(II)	HWIR	Ja97	soil	838	2.92	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
256	Cu(II)	HWIR	Ja97	soil	701	2.85	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
258	Cu(II)	HWIR	Ja97	soil	529	2.72	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
251	Cu(II)	Listing	Ge82	soil	500	2.7	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
259	Cu(II)	HWIR	Ja97	soil	452	2.66	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
257	Cu(II)	HWIR	Ja97	soil	322	2.51	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
252	Cu(II)	Listing	Ge82	soil	155	2.19	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
265	Cu(II)	HWIR	Ja97	soil	135	2.13	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
253	Cu(II)	HWIR	Ja97	soil	109	2.04	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
255	Cu(II)	HWIR	Ja97	soil	92	1.96	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
266	Cu(II)	HWIR	Ja97	soil	88	1.94	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
264	Cu(II)	HWIR	Ja97	soil	67	1.83	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
262	Cu(II)	HWIR	Ja97	soil	38	1.58	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
254	Cu(II)	HWIR	Ja97	soil	35	1.54	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
261	Cu(II)	HWIR	Ja97	soil	25	1.4	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
275	Hg(II)	HWIR	Ly97	soil	10526	4.02				data from Table 1 (depth-weighted average) computed as "mean" values within a depth interval as the ratio of mean soil conc over mean water conc.
277	Hg(II)	HWIR	Ly97	soil	8328	3.92				data from Table 2 (depth-weighted average)
276	Hg(II)	HWIR	Ly97	soil	8000	3.9				data from Table 2
279	Hg(II)	Listing	Ge82	soil	7600	3.88	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
280	Hg(II)	Listing	Ge82	soil	4500	3.65	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
278	Hg(II)	HWIR	Sc97	soil	1924	3.28	4.5			estimated depth-weighted average from a plot of Kd vs depth for a single soil type (iron-humus podozol).
281	Hg(II)	Listing	Bi91	aquifer	2.2	0.34		0.01 M NaCl	column	result for the lowest total Hg concentration listed in Table 3
273	Hg(II)	Listing	Mac93	soil	0.78	-0.11	4.5	not specified	batch (L:S not specified)	average value; no units reported
274	Hg(II)	Listing	Mac93	aquifer	0.22	-0.66	4.5	not specified	batch (L:S not specified)	average value; no units reported

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
288	Mn	Listing	Mi82	aquifer	4100	3.61	8	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
284	Mn	Listing	Mi82	aquifer	1000	3	8.2	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
289	Mn	Listing	Mi82	aquifer	430	2.63	7	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
282	Mn	Listing	Ya95	soil	271	2.43	5.85	rainwater	batch (30 mL:3 g)	median value from Table III (36 soils)
292	Mn	Listing	Mi82	aquifer	160	2.2	6.8	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
285	Mn	Listing	Mi82	aquifer	130	2.11	6.2	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
286	Mn	Listing	Mi82	aquifer	96	1.98	8.4	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
290	Mn	Listing	Mi82	aquifer	86	1.93	6.4	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
291	Mn	Listing	Mi82	aquifer	49	1.69	6.4	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
293	Mn	Listing	Sh89	soil	44	1.64	6.7	0.1 M ammonium acetate	batch-radioisotope (50 mL: 2.5 cc)	geometric mean from table 2, pH and soil properties recorded are mean values; paper presents evidence of log-normal distribution for Kd in these soils
283	Mn	Listing	St86	soil	36	1.56		not specified	batch (L:S not specified)	selected only the two values for bulk soil under ambient conditions; did not use values for organic-rich root channel macropores; no units given, assumed L/kg.
287	Mn	Listing	Mi82	aquifer	34	1.53	8.3	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
297	Mo(VI)	Listing	Ge82	soil	162.5	2.21	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
294	Mo(VI)	HWIR	Is93	soil	148	2.17	5.3			calculated from sorbed conc data plotted against solution conc for two soil horizons of one soil; values recorded are mean Kd, pH, POC
295	Mo(VI)	HWIR	Sh91a	soil	10.6	1.02	5.7			depth-weighted average from 4-year study of a sandy soil originally spiked with Mo(VI)
298	Mo(VI)	Listing	St95	aquifer	6.7	0.83	5.7	groundwater	batch (30 mL:30 g)	estimated from % sorbed in Fig. 5 at ambient pH (5.7) for uncontaminated well (Sample F347-20); solid conc = 1kg/L, total MoO4 = 5E-05 M
296	Mo(VI)	Listing	Ge82	soil	2.75	0.44	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
302	Ni(II)	Listing	Ch96	aquifer	7250	3.86	8.75	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
335	Ni(II)	HWIR	Ja97	soil	5749	3.76	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
338	Ni(II)	Listing	Ba92	aquifer	4750	3.68		groundwater	batch (L:S not specified)	mean of two 0.45um filtered replicates; Total_Ni=9e-09 M; pH not specified; used Table 7 entries w/o added DOC.
301	Ni(II)	Listing	Ch96	aquifer	4510	3.65	8.87	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
313	Ni(II)	Listing	Ch96	aquifer	4370	3.64	8.83	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
336	Ni(II)	HWIR	Ja97	soil	4113	3.61	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
326	Ni(II)	HWIR	Ja97	soil	3151	3.5	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
308	Ni(II)	Listing	Ch96	aquifer	2750	3.44	8.87	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
337	Ni(II)	HWIR	Ja97	soil	2310	3.36	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
334	Ni(II)	HWIR	Ja97	soil	2163	3.34	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
333	Ni(II)	HWIR	Ja97	soil	1857	3.27	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
324	Ni(II)	HWIR	Ja97	soil	1843	3.27	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
321	Ni(II)	HWIR	Ja97	soil	1660	3.22	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
314	Ni(II)	Listing	Ch96	aquifer	1510	3.18	8.47	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
305	Ni(II)	Listing	Ch96	aquifer	1430	3.16	8.51	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
325	Ni(II)	HWIR	Ja97	soil	1285	3.11	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
322	Ni(II)	HWIR	Ja97	soil	1255	3.1	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
319	Ni(II)	HWIR	Ja97	soil	1088	3.04	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
332	Ni(II)	HWIR	Ja97	soil	744	2.87	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
300	Ni(II)	Listing	Ch96	aquifer	450	2.65	7.96	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
307	Ni(II)	Listing	Ch96	aquifer	440	2.64	8.01	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
311	Ni(II)	Listing	Ch96	aquifer	420	2.62	8.46	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
331	Ni(II)	HWIR	Ja97	soil	376	2.58	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
317	Ni(II)	Listing	Ge82	soil	350	2.54	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
306	Ni(II)	Listing	Ch96	aquifer	310	2.49	8.41	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
320	Ni(II)	HWIR	Ja97	soil	292	2.47	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
303	Ni(II)	Listing	Ch96	aquifer	250	2.4	7.85	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
323	Ni(II)	HWIR	Ja97	soil	243	2.39	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
329	Ni(II)	HWIR	Ja97	soil	236	2.37	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
330	Ni(II)	HWIR	Ja97	soil	185	2.27	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
328	Ni(II)	HWIR	Ja97	soil	130	2.11	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
327	Ni(II)	HWIR	Ja97	soil	115	2.06	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
318	Ni(II)	Listing	Ge82	soil	49.5	1.69	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
310	Ni(II)	Listing	Ch96	aquifer	40	1.6	6.77	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
312	Ni(II)	Listing	Ch96	aquifer	40	1.6	5.83	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
315	Ni(II)	Listing	Ch96	aquifer	24	1.38	5.86	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
299	Ni(II)	Listing	Ch96	aquifer	18	1.26	6.19	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
309	Ni(II)	Listing	Ch96	aquifer	12	1.08	5.66	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
316	Ni(II)	Listing	Ch96	aquifer	7	0.85	5.28	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
304	Ni(II)	Listing	Ch96	aquifer	3	0.48	4.91	0.001 M CaCl2	batch (50 mL:10 g)	data from Table 2 (p. 79): log Kd = 0.72pH - 3.03
371	Pb(II)	HWIR	Ja97	soil	67856	4.83	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
360	Pb(II)	HWIR	Ja97	soil	60311	4.78	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
345	Pb(II)	HWIR	Sh91b	soil	60000	4.78	7			agricultural soil: loam
343	Pb(II)	HWIR	Sh91b	soil	60000	4.78	7			agricultural soil: clay loam
349	Pb(II)	HWIR	Sh89b	soil	59000	4.77	7.4			
373	Pb(II)	OAR	Rh92	soil	46000	4.66	8.35	NA	batch	mid-point of range, batch tracer studies (Initial activities 2.38 23.4 μµCi/1; <0.01 OC))
369	Pb(II)	HWIR	Ja97	soil	45502	4.66	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
357	Pb(II)	HWIR	Ja97	soil	42250	4.63	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
367	Pb(II)	HWIR	Ja97	soil	37379	4.57	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
366	Pb(II)	HWIR	Ja97	soil	36930	4.57	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
356	Pb(II)	HWIR	Ja97	soil	34727	4.54	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
346	Pb(II)	HWIR	Sh91b	soil	30000	4.48	5.5			boreal acidic organic soil: sedge peat
368	Pb(II)	HWIR	Ja97	soil	27722	4.44	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
353	Pb(II)	HWIR	Ja97	soil	22944	4.36	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
344	Pb(II)	HWIR	Sh91b	soil	21000	4.32	7.3			agricultural soil: gleysol loam
370	Pb(II)	HWIR	Ja97	soil	16973	4.23	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
359	Pb(II)	HWIR	Ja97	soil	12514	4.1	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
347	Pb(II)	HWIR	Sh91b	soil	9000	3.95	4.8			boreal acidic organic soil: sphagnum peat
363	Pb(II)	HWIR	Ja97	soil	5923	3.77	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
358	Pb(II)	HWIR	Ja97	soil	5310	3.73	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
351	Pb(II)	Listing	Ge82	soil	4250	3.63	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
377	Pb(II)	OAR	Ha81	aquifer	4000	3.6	7	NA	NA	OAR (Table F.!); little information provided
365	Pb(II)	HWIR	Ja97	soil	3550	3.55	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
354	Pb(II)	HWIR	Ja97	soil	3428	3.54	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
355	Pb(II)	HWIR	Ja97	soil	2637	3.42	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
376	Pb(II)	OAR	Ha81	aquifer	1500	3.18	5.75	NA	NA	OAR (Table F.!); little information provided
361	Pb(II)	HWIR	Ja97	soil	1326	3.12	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
362	Pb(II)	HWIR	Ja97	soil	1159	3.06	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
364	Pb(II)	HWIR	Ja97	soil	916	2.96	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
352	Pb(II)	Listing	Ge82	soil	750	2.88	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
341	Pb(II)	HWIR	Me94	soil	126	2.1	4.1			acidic soil polluted with mine waste in England

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
375	Pb(II)	OAR	Ha81	aquifer	100	2	4.5	NA	NA	OAR (Table F.!); little information provided
342	Pb(II)	HWIR	Me94	soil	96	1.98	3.4			acidic soil polluted with mine waste in England
339	Pb(II)	HWIR	Me94	soil	93	1.97	4.6			acidic soil polluted with mine waste in England
372	Pb(II)	Listing	Fu96	aquifer	24.4	1.39	5.3	artificial groundwater	batch (20:1)	mean sorbed from multiple cores sampled; Fig 2 and Tbl 4 in Da93; Fe, Al, Mn anal. avail. (Tbl. 1); total Pb is 20 umol/L
374	Pb(II)	OAR	Ha81	aquifer	20	1.3	2	NA	NA	OAR (Table F.!); little information provided
348	Pb(II)	HWIR	Sh91b	soil	19.8	1.3	4.9			boreal acidic sandy soil: brunisol sand
350	Pb(II)	HWIR	Sh89b	soil	19	1.28	4.9			
340	Pb(II)	HWIR	Me94	soil	14	1.15	4			acidic soil polluted with mine waste in England
378	Sb(III)	Listing	Ge82	soil	14	1.15	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
379	Sb(III)	Listing	Ge82	soil	11	1.04	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
387	Se(IV)	HWIR	Fi91	soil	46.7	1.67	8.3			Kd from plot of %sorbed vs time (Fig 2); used longest time interval for Soil CS in 0.005M CaSO4 solution
389	Se(IV)	HWIR	Sa94	soil	35	1.54	5			Kd from plot of sorbed vs dissolved for metal titration (Fig 1); value is for low added Se for Mukaiyama whole soil
382	Se(IV)	HWIR	Ne87	soil	34.5	1.54	5.5			Kd from plot of %sorbed vs pH (Fig 2); 3 points selected for this soil to describe the Kd vs pH response
385	Se(IV)	HWIR	Ch89	soil	31	1.5	6.5			Kd from plot of %sorbed vs time (Fig 1); used longest time interval for Ronhave whole soil
386	Se(IV)	HWIR	Fi91	soil	30	1.48	8.3			Kd from plot of %sorbed vs time (Fig 2); used longest time interval for Site 3 soil in 0.1M NaCl
392	Se(IV)	Listing	Ge82	soil	27.5	1.44	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
393	Se(IV)	Listing	Ge82	soil	26	1.41	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
388	Se(IV)	HWIR	Ch89	soil	23.5	1.37	6.6			Kd from plot of %sorbed vs time (Fig 2); used longest time interval for Studsgaard whole soil

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
381	Se(IV)	HWIR	Ne87	soil	18.9	1.28	4.2			Kd from plot of %sorbed vs pH (Fig 2); 3 points selected for this soil to describe the Kd vs pH response
390	Se(IV)	HWIR	Sa94	soil	16.5	1.22	5			Kd from plot of sorbed vs dissolved for metal titration (Fig 1); value is for low added Se for Tanashi whole soil
383	Se(IV)	HWIR	Ne87	soil	10.7	1.03	5.9			Kd from plot of %sorbed vs pH (Fig 2); 3 points selected for this soil to describe the Kd vs pH response
391	Se(IV)	Listing	Fi90	soil	10.5	1.02	8.3	0.1 M NaCl	batch (150 mL:7.5 g)	median value of three Freundlich values from Table 1
384	Se(IV)	HWIR	Ne87	soil	9.2	0.97	6			Kd from plot of %sorbed vs pH (Fig 2); 3 points selected for this soil to describe the Kd vs pH response
380	Se(IV)	HWIR	Ne87	soil	2.17	0.34	8.1			Kd from plot of %sorbed vs pH (Fig 2); 3 points selected for this soil to describe the Kd vs pH response
394	Sn	Listing	Ge82	soil	7750	3.89	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
395	Sn	Listing	Ge82	soil	2150	3.33	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
396	V(IV)	Listing	Ge82	soil	330	2.52	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
397	V(IV)	Listing	Ge82	soil	75	1.88	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
427	Zn(II)	Listing	Mi82	aquifer	28000	4.45	8	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
422	Zn(II)	Listing	Mi82	aquifer	15000	4.18	8.2	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
424	Zn(II)	Listing	Mi82	aquifer	14000	4.15	8.2	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
428	Zn(II)	Listing	Mi82	aquifer	9100	3.96	7	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
420	Zn(II)	HWIR	Ja97	soil	6762	3.83	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
409	Zn(II)	HWIR	Ja97	soil	6226	3.79	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
437	Zn(II)	Listing	Le98	soil	5667	3.75	6.51	0.01 N NaNO3	batch (100:1)	values at soil pH from Table 3 (Kd at other pH's also presented)
425	Zn(II)	Listing	Mi82	aquifer	5600	3.75	8.4	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
421	Zn(II)	HWIR	Ja97	soil	5472	3.74	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
419	Zn(II)	HWIR	Ja97	soil	5112	3.71	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
429	Zn(II)	Listing	Mi82	aquifer	5100	3.71	6.4	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
430	Zn(II)	Listing	Mi82	aquifer	5000	3.7	6.4	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
417	Zn(II)	HWIR	Ja97	soil	3698	3.57	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
423	Zn(II)	Listing	Mi82	aquifer	3200	3.51	6.2	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
426	Zn(II)	Listing	Mi82	aquifer	3000	3.48	8.3	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
406	Zn(II)	HWIR	Ja97	soil	2800	3.45	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
431	Zn(II)	Listing	Mi82	aquifer	2700	3.43	6.8	groundwater	batch-radioisotope (10:1)	from Table II; trace concentration of metal (less than or equal to 1umol/L)
407	Zn(II)	HWIR	Ja97	soil	2438	3.39	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
405	Zn(II)	HWIR	Ja97	soil	2245	3.35	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
400	Zn(II)	Listing	Ge82	soil	2050	3.31	7.8			middle (7.8) of pH range (7.5 - 8.0) reported for a sandy loam soil
433	Zn(II)	Listing	Le98	soil	1989	3.3	6.89	0.01 N NaNO3	batch (100:1)	values at soil pH from Table 3 (Kd at other pH's also presented)
399	Zn(II)	Listing	Ya95	soil	1756	3.24	5.85	rainwater	batch (30 mL:3 g)	median value from Table III (36 soils)
408	Zn(II)	HWIR	Ja97	soil	1299	3.11	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils

(continued)

Table H-18. (continued)

ID	Metal Species	Study	Ref.	Medium	Kd (L/kg)	Log Kd	pH	Extractant	Method	Comments
402	Zn(II)	HWIR	Ja97	soil	1294	3.11	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
418	Zn(II)	HWIR	Ja97	soil	1278	3.11	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
435	Zn(II)	Listing	Le98	soil	995	3	6.38	0.01 N NaNO3	batch (100:1)	values at soil pH from Table 3 (Kd at other pH's also presented)
404	Zn(II)	HWIR	Ja97	soil	604	2.78	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
416	Zn(II)	HWIR	Ja97	soil	422	2.63	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
412	Zn(II)	HWIR	Ja97	soil	154	2.19	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
403	Zn(II)	HWIR	Ja97	soil	73	1.86	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
436	Zn(II)	Listing	Le98	soil	72.5	1.86	4.81	0.01 N NaNO3	batch (100:1)	values at soil pH from Table 3 (Kd at other pH's also presented)
401	Zn(II)	Listing	Ge82	soil	55.5	1.74	4.8			middle (4.8) of pH range (4.5 - 5.0) reported for a sandy soil
398	Zn(II)	HWIR	Sc88	soil	41	1.61	3.7			data from a single forest soil; reported "mean" Kd; Kd reported to exhibit a log-normal distrib
411	Zn(II)	HWIR	Ja97	soil	41	1.61	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
414	Zn(II)	HWIR	Ja97	soil	38	1.58	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
413	Zn(II)	HWIR	Ja97	soil	34	1.53	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
434	Zn(II)	Listing	Le98	soil	33.8	1.53	3.96	0.01 N NaNO3	batch (100:1)	values at soil pH from Table 3 (Kd at other pH's also presented)
410	Zn(II)	HWIR	Ja97	soil	23	1.36	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
415	Zn(II)	HWIR	Ja97	soil	6	0.78	6.4			pH, POC, DOC, etc., are median values for the collection of 20 soils
432	Zn(II)	Listing	Fu96	aquifer	2.7	0.43	5.3	artificial groundwater	batch (20:1)	mean sorbed from multiple cores sampled; Fig 2 and Tbl 4 in Da93; Fe, Al, Mn anal. avail. (Tbl 1); total Zn is 5 umol/L

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Appendix I

Site Data

Section I.1 Soil Characterization Methodology

Table I.1-1 Soil Parameters Correlated to Soil Texture
Table I.1-2 Soil Moisture Coefficient *b* Values
Table I.1-3 Depth to Root Zone Values
Table I.1-4 Field Capacity (FC) and Wilting Point (WP) Values
Table I.1-5 SCS Curve Number Values
Table I.1-6 Default Flow Lengths by Shape

Section I.2 Site-Specific Model Parameters

Table I.2-1 Summary of Site-Specific Parameters Used in Various Models
Table I.2-2 Site-Specific Surface Soil Parameters
Table I.2-3 Site-Specific Subsurface Soil Parameters
Table I.2-4 Site-Specific Inputs to the General Soil Column Model
Table I.2-5 Site-Specific Meteorological Parameters

Section I.3 Characterization of Aquifer Types for Each Site

Table I.3-1 Hydrogeologic Data for Paints Meteorological Stations

Section I.4 References

Section I.1

Soil Characterization Methodology

I.1.1 Methodology

Soils were characterized using the soil parameters presented in Tables I.1-1 through I.1-6. The methodology used to characterize soils begins with geographic information systems (GIS) programs (in Arc Macro Language [AML]) that overlay a 20-mile radius around each meteorological station on the STATSGO coverage and determine the STATSGO map units and their areas within the radius. These data are then used to derive soil properties for this analysis.

The soil data processing effort bases all collected soil properties on the predominant soil texture for each STATSGO map unit. Predominant texture was determined both for surface soils (top 20 cm) and the entire soil column (to represent the vadose zone) from CONUS data. For surface soils, the predominant texture is the thickest, weighted by depth, soil texture for the top three CONUS layers (20 cm). Note that where there was a tie (5 of the 213 map units used in this analysis), the texture of the top two layers was used as the predominant soil texture for that map unit. Also note that there were 13 map units that did not have one of the common soil types. Of these, seven were water and six were organic matter. Soil parameters based on soil texture could not be derived for these 13 map units and, where they occur, they were excluded from the soil data for the meteorological stations. Soil column texture was obtained in a similar manner, except that all CONUS layers were used.

I.1.2 Soil Properties

Once predominant soil textures were determined for each map unit, the areas of the map units within the 20-mile radius surrounding each station were used to determine the predominant soil type for each meteorological station. These predominant textures were then used to determine the remaining soil properties as described below.

I.1.2.1 <u>Soil Properties Based on Relationship with Predominant Texture</u>. Several soil hydrologic properties were derived directly from predominant texture using database lookup tables relating mean properties to texture class.

Table I.1-1. Soil Parameters Correlated to Soil Texture

Soil Texture	Ksat (cm/h)	Alpha (1/cm)	Beta	WCS	RHOB (g/cm^3)	WCR
Clay (C)	0.20	0.008	1.09	0.38	1.643	0.068
Clay loam (CL)	0.26	0.019	1.31	0.41	1.5635	0.095
Loam (L)	1.04	0.036	1.56	0.43	1.5105	0.078
Loamy sand (LS)	14.59	0.124	2.28	0.41	1.5635	0.057
Silt (SI)	0.25	0.016	1.37	0.46	1.431	0.034
Silt loam (SIL)	0.45	0.020	1.41	0.45	1.4575	0.067
Silty clay (SIC)	0.02	0.005	1.09	0.36	1.696	0.070
Silty clay loam (SICL)	0.07	0.010	1.23	0.43	1.5105	0.089
Sand (S)	29.70	0.145	2.68	0.43	1.5105	0.045
Sandy clay (SC)	0.12	0.027	1.23	0.38	1.643	0.100
Sandy clay loam (SCL)	1.31	0.059	1.48	0.39	1.6165	0.100
Sandy loam (SL)	4.42	0.075	1.89	0.41	1.5635	0.065

Source: Carsel and Parrish (1988), U.S. EPA (1997).

- **Saturated hydraulic conductivity (cm/h)**. Collected for both the surface soil (*Ksat_top20*) and the entire soil column (*Ksat*, *KsatC*, *VadSATK*); relationship from Carsel and Parrish (1988).

- **Moisture retention parameter alpha (1/cm).** Collected for the entire soil column (*VadALPHA*); relationship from Carsel and Parrish (1988).

- **Moisture retention parameter beta (unitless).** Collected for the entire soil column (*VadBETA*); relationship from Carsel and Parrish (1988).

- **Saturated water content (unitless).** Collected for both the surface soil (*WCS_top20*) and the entire soil column (*VadWCS*, *WCS*, *WCS_C*); relationship from Carsel and Parrish (1988).

- **Bulk density (g/cm^3)**. Calculated for both the surface soil (*BD_top20*) and the entire soil column (*RHOB*); relationship from saturated water content using the equation

$$\rho_b = 2.65(1 - \varphi) \qquad \text{(I-1)}$$

where

ρ_b	=	bulk density of the soil (U.S. EPA, 1997)
2.65	=	particle density in g/cm^3 (assumed to be quartz)
φ	=	saturated water content.

- **Residual water content (L/L).** Collected for the entire soil column (*VadWCR*); relationship from Carsel and Parrish (1988).

- **Soil moisture coefficient (unitless).** Collected for both the surface soil (*SMb_top20*) and the entire soil column (*SMbC, SMbS*); relationship from Clapp and Hornberger (1978).

- **Depth to root zone (cm).** Collected for the entire soil column (*DRZ*) using a Dunne and Leopold (1978) table of rooting depth by vegetation type and soil texture. Anderson land use descriptions obtained from GIRAS coverages for the 20-mile radius around each meteorological station were used to match a vegetation type from Dunne and Leopold (1978) to an Anderson land use code. Because Dunne and Leopold included only 5 soil textures and there are 13 basic CONUS textures, the 5 textures were mapped across the CONUS textures as shown in Table I.1-3. Because there were multiple land uses for each station, an area-weighted average root zone depth was calculated for each station.

I.1.2.2 Soil Parameters by Relationship with Hydrologic Group. The following soil parameters are all based on the average hydrologic soil group for the 20-mile radius around each station. A table of hydrologic soil group by map unit was created using STATSGO data of hydrologic soil group by component (Schwarz and Alexander, 1995). Using the predominant texture from CONUS for each map unit, only the components with the same STATSGO texture as CONUS were used to obtain values for hydrologic soil group by component, then the hydrologic soil groups were averaged (weighted by component percent) using the conversion: A=1, B=2, C=3, and D=4. After the average was calculated, the numbers were converted back to letters using the same conversion, resulting in a table of hydrologic soil group by map unit based on the predominant texture for that map unit.

Table I.1-2. Soil Moisture Coefficient *b* Values

Soil Texture	Soil Moisture Coefficient *b* Values
Ssand	4.05
Loamy sand	4.38
Sandy loam	4.90
Silt loam	5.30
Loam	5.39
Sandy clay loam	7.12
Silty clay loam	7.75
Clay loam	8.52
Sandy clay	10.4
Silty clay	10.4
Clay	11.4

Source: Clapp and Hornberger (1978).

Table I.1-3. Depth to Root Zone Values

Anderson Code (GIRAS)	Vegetation (Dunne & Leopold, 1978)	Depth to Root Zone [a]				
		Fine Sand (S)	Fine Sandy Loam (LS, SL)	Silt Loam (L, OM, SI, SIL)	Clay Loam (CL, SCL, SICL)	Clay (C, SC, SIC)
11, 12, 13, 14, 15, 16, 17, 22	Orchards	1.5	1.67	1.5	1	0.67
21, 24	Moderately deep-rooted crops	0.75	1	1	0.8	0.5
23	Shallow-rooted crops	0.5	0.5	0.62	0.4	0.25
31, 32, 33, 81, 82, 84, 85	Deep-rooted crops	1	1	1.25	1	0.67
41, 42, 43, 61	Mature forest	2.5	2	2	1.6	1.17
71, 72, 73, 74, 75, 76	None - no vegetation	0	0	0	0	0

[a] Extracted from Dunne and Leopold (1978); assignment to soil textures shown in parentheses.

Using only the map units in the 20-mile radius with the same predominant texture as the entire station, an average hydrologic soil group for the station was calculated using the same letter-to-number conversion previously described. Note that hydrologic soil group applies to the entire soil column and is not layer-specific. Mean values by hydrologic group were obtained using the following relationships.

- **Soil moisture field capacity (volume %)**. A single field capacity value (*SMFC*) was obtained by hydrologic soil group by averaging the layered property values from Carsel et al. (1988). Table I.1-4 presents the mean value for field capacity by hydrologic soil group and layer.

Table I.1-4. Field Capacity (FC) and Wilting Point (WP) Values

Hydrologic Group	Layer	FC	WP
A	1	9.4	3.1
A	2	8.1	2.3
A	3	5.9	2.1
A	4	5.8	1.9
B	1	19.1	8.7
B	2	18.8	9.3
B	3	18.7	8.9
B	4	17.5	8.4
C	1	22.5	10.4
C	2	23.2	12.1
C	3	22.9	11.9
C	4	21.3	11.5
D	1	24.2	13.8
D	2	26.3	17.0
D	3	25.6	16.3
D	4	24.4	15.1

Source: Carsel et al. (1988).

- **Soil moisture wilting point (volume %).** A single wilting point value (*SMWP*) was obtained by hydrologic soil group by averaging the layered property values from Carsel et al. (1988). Table I.1-4 also lists the mean value for wilting point by hydrologic soil group and layer.

- **SCS curve number (unitless).** A land use area-weighted average Soil Conservation Service (SCS) curve number value (*CNwmu*) was calculated for the 20-mile radius around each meteorological station. The lookup table was based on a USDA (1986) table of curve numbers by cover type and hydrologic soil group. The cover type descriptions from the USDA (1986) table for curve numbers were compared to the Anderson land use descriptions to match a cover type to each Anderson land use code. The resulting table consists of SCS curve numbers by Anderson land use code and hydrologic soil group.

I.1.2.3 <u>Parameters Collected Directly from STATSGO-Based Data Sources</u>. Several variables were obtained directly from STATSGO (Schwarz and Alexander, 1995). Although they are not derived from soil texture, they were extracted and averaged based only on soil map units with the predominant texture to ensure consistent soil properties.

- **Soil pH** (pH units). Soil pH for the entire soil column (*VadPh*) was calculated for each station as an area-weighted average across all map units with the predominant texture. Soil pH by component was first calculated as a depth-weighted average of STATSGO pH by layer, then pH by component was averaged weighted by percent of each component in the map unit to obtain a pH for the entire soil column by map unit. Surface soil pH (*WSpH*) was calculated similarly, except that only the top three layers were depth-averaged.

- **USLE erodibility factor - top 20 cm** (ton/acre). An area-weighted average erodibility factor for the top 20 cm of soil (*K_top20*) was calculated from STATSGO data by layer and component. STATSGO layer data were translated into K values using standardized CONUS layers and calculating a depth-weighted average value. Further, a component percent-weighted average K was calculated for each CONUS layer across all components contained in each map unit. The resulting table contains K values by map unit and standardized CONUS layer. To get one value for K by map unit for the top 20 cm of soil, a depth-weighted average for the top three CONUS layers was calculated. The final K value by meteorological station was obtained by map unit using only the map units with the predominant surface soil texture for the station.

- **Percent organic matter - entire soil column** (percent). Percent organic matter (*POM*) for the entire soil column at each station was calculated by taking an area-weighted average from USSOILS across all map units with the predominant texture.

Table I.1-5. SCS Curve Number Values

Anderson Code (GIRAS Land Use)	Assumed Cover Type (USDA, 1986)	SCS Curve Number[a]			
		A	**B**	**C**	**D**
11- Residential	Residential (averaged over different lot sizes)	58	73	82	86
12 - Commercial and services	Commercial and business	89	92	94	95
13, 15 - Industrial/commercial services	Industrial	81	88	91	93
14 -Transportation, communication, utilities	Paved roads, open ditches (with right of way)	83	89	92	93
16 -Mixed urban or builtup land	Commercial and business, industrial, residential – one-fourth acre or less (average)	80	87	91	93
17 - Other urban or builtup land	Urban open space (fair)	49	69	79	84
21 - Cropland and pasture	Mean cropland and pasture – fair (average)	57	72	80	85
22 - Orchards, groves, vineyards, nurseries, and ornamental horticultural land	Woods – grass combination (fair)	43	65	76	82
23, 24 - Confined feeding operations/ other agricultural land	Farmsteads	59	74	82	86
31 - Herbaceous rangeland	Herbaceous and pasture/grassland/range (average)	49	70	80	87
32 - Shrub and brush rangeland	Oak-aspen, desert shrub, sagebrush, brush – fair (average)	45	57	68	74
33 - Mixed rangeland	31, 32 (average)	47	64	74	81
41, 42, 43 - Deciduous/evergreen/ mixed forestland	Woods (fair)	36	60	73	79
71, 72, 73, 76 - Barren land	Bare ground/newly graded areas	77	86	91	94
74 - Bare exposed rock	Paved parking lots/bare rock	98	98	98	98
75 - Strip mines, quarries, gravel pits	Gravel roads	76	85	89	91

[a] Extracted or calculated from USDA (1986) using assumed cover type. A, B, C, and D are hydrologic soil groups.

- **Fraction organic carbon - entire soil column** (mass fraction)**.** Fraction organic carbon for the entire soil column (*focC*, *focS_lf*) was calculated from percent organic matter by dividing the percent organic matter by 174. Equation is from the *EPACMTP User's Guide* (U.S. EPA, 1997).

- **Fraction organic carbon - top 20 cm** (mass fraction)**.** An area-weighted average fraction organic carbon for surface soils (*foc_top20*) was calculated for each station using only the map units with the predominant surface soil texture by dividing the percent organic matter by 174 (U.S. EPA, 1997). Percent organic matter for the top 20 cm of soil was obtained from STATSGO organic matter data by layer and component (Schwarz and Alexander, 1995). Organic matter values were translated from STATSGO layer and component into standardized CONUS layers using the same methodology described for the USLE erodibility factor K. Then a depth-weighted average percent organic matter was calculated for the top three CONUS layers (top 20 cm of soil).

Length/Slope Factor. The USLE's length slope factor (*LS*) was derived from STATSGO slope data. Percent slope (*Theta*), which is a property of the entire soil column in STATSGO, was obtained from USSOILS by map unit using only the map units with the predominant texture for the station. An area-weighted average slope was calculated for the station. Length (*Length*, ft) was then obtained from a Lightle and Weesies (1998) lookup table of default flow lengths by slope, using slope values rounded to the nearest integer. All slopes less than 0.5 were given the length corresponding to 0.5 and all slopes greater than 24 were given the length corresponding to 24. The USLE length/slope factor LS (unitless) was then calculated using the equation from Williams and Berndt (1977):

$$LS = (L/72.6)^{m}(0.065 + 0.0454S + 0.0065S^{2}) \qquad \text{(I-2)}$$

where

S = slope in percent
L = flow length

and

m = 0.2 for slope <1 percent
m = 0.3 for slope ≥ 1 percent and <3 percent
m = 0.4 for slope ≥ 3 percent and <5 percent
m = 0.5 for slope ≥ 5 percent.

Table I.1-6. Default Flow Lengths by Slope

Slope	Length (ft)	Slope	Length (ft)
≤0.5	100	13	90
1	200	14	80
2	300	15	70
3	200	16	60
4	180	17	60
5	160	18	50
6	150	19	50
7	140	20	50
8	130	21	50
9	125	22	50
10	120	23	50
11	110	≥24	50
12	100		

Source: Lightle and Weesies, 1998.

Section I.2

Site-Specific Model Parameters

Table I.2-1. Summary of Site-Specific Parameters Used in Various Models

Parameter Name	Parameter	General Soil Column Model	Source Models			Fate and Transport Models		Table	Reference
			Landfills	SIs	Tank	GW	AG		
Aquifer									
Average aquifer temperature	AquTemp					Yes			van der Leeden, 1990
Cover Soil									
Fraction organic carbon (cover soil)	focC		Yes					I.2.3	USDA, 1994
Saturated hydraulic conductivity (LF cover soil)	KsatC		Yes					I.2.3	Carsel and Parrish, 1988
Saturated water content (cover soil, total porosity)	WCS_C		Yes					I.2.3	Carsel and Parrish, 1988
Soil moisture coefficient b (LF cover soil)	SMbC		Yes					I.2.3	Clapp and Hornberger, 1978
Meteorological									
Average annual recharge	Q					Yes	Yes	I.2.5	Soil Column Model Results
Average annual runoff	Rf						Yes	I.2.5	Geraghty et al., 1973
Average waste/source temperature	SrcTemp			Yes	Yes			I.2.5	U.S. DOC and U.S. DOE, 1999
Mean annual windspeed	uw						Yes	I.2.5	U.S. DOC and U.S. DOE, 1999
USLE rainfall/erosivity factor	R						Yes	I.2.5	Geraghty et al., 1973
Subsurface Soil									
Average vadose zone pH	VadPH					Yes		I.2.3	USDA, 1994
Average vadose zone temperature	VadTemp		Yes					I.2.3	van der Leeden, 1990
Bulk density of soil	RHOB					Yes		I.2.3	Carsel and Parrish, 1988
Depth (root zone, all subareas)	DRZ	Yes						I.2.4	Dunne and Leopold, 1978
Fraction organic carbon (subsoil)	focS_lf		Yes					I.2.3	USDA, 1994
Percent organic matter	POM					Yes		I.2.3	Schwartz and Alexander, 1995
Residual water content	VadWCR					Yes		I.2.3	Carsel and Parrish, 1988
Saturated hydraulic conductivity (subsoil)	VadSATK	Yes	Yes	Yes		Yes		I.2.3	Carsel and Parrish, 1988
Saturated water content (subsoil)	VadWCS	Yes	Yes			Yes		I.2.3	Carsel and Parrish, 1988
SCS curve number (WMU)	CNwmu	Yes						I.2.4	USDA, 1986
Soil moisture coefficient b (subsoil)	SMbS		Yes					I.2.3	Clapp and Hornberger, 1978
Soil moisture field capacity	SMFC	Yes						I.2.4	Carsel et al., 1988
Soil moisture wilting point	SMWP	Yes						I.2.4	Carsel et al., 1988
Soil retention parameter alpha (subsoil)	VadALPHA			Yes		Yes		I.2.3	Carsel and Parrish, 1988

Table I.2-1. Summary of Site-Specific Parameters Used in Various Models

Parameter Name	Parameter	General Soil Column Model	Source Models			Fate and Transport Models		Table	Reference
			Landfills	SIs	Tank	GW	AG		
Soil retention parameter beta (subsoil)	VadBETA			Yes		Yes		I.2.3	Carsel and Parrish, 1988
Surface Soil									
Dry bulk soil density; top 20 cm of soil	BD_top20						Yes	I.2.2	Carsel and Parrish, 1988
Fraction organic carbon; top 20 cm of soil	foc_top20						Yes	I.2.2	USDA, 1994
Saturated hydraulic conductivity; top 20 cm of soil	Ksat_top20						Yes	I.2.2	Carsel and Parrish, 1988
Saturated water content (total porosity); top 20 cm of soil(can be calculated from bulk density)	WCS_top20						Yes	I.2.2	Carsel and Parrish, 1988
Soil moisture coefficient b; top 20 cm of soil	SMb_top20						Yes	I.2.2	Clapp and Hornberger, 1978
USLE									
USLE erodibility factor; top 20 cm of soil	K_top20						Yes	I.2.2	USDA, 1994
USLE length-slope factor (calculated)	LS						Yes	I.2.2	See Equation I-1

a. All cover soil parameters were assumed to be equivalent to subsurface soil parameters.

b. Source temperature was set equal to average air temperature for each location modeled.

SI = Surface impoundment.

GW = Groundwater model.

AG = Aboveground model.

Table I.2-2. Site-Specific Surface Soil Parameters

City	Met Station ID	Soil Texture	pH	Dry Bulk Density (g/cm³)	Saturated Water Content (mL/cm³)	Saturated Hydraulic Conductivity (cm/yr)	Soil Moisture Coefficient (unitless)	Fraction Organic Carbon (unitless)	USLE Erodibility Factor (ton/acre)	USLE Length-Slope Factor (unitless)
Albany, NY	14735	Silt loam	5.833	1.4575	0.45	0.45	5.3	0.026	0.365	1.460
Atlanta, GA	13874	Sandy loam	5.430	1.5635	0.41	4.42	4.9	0.005	0.274	1.073
Baltimore, MD	93721	Silt loam	5.077	1.4575	0.45	0.45	5.3	0.015	0.364	1.217
Boston, MA	14739	Sandy loam	5.024	1.5635	0.41	4.42	4.9	0.080	0.257	0.866
Boulder, CO	94018	Sandy loam	6.491	1.5635	0.41	4.42	4.9	0.011	0.294	6.503
Chicago, IL	94846	Silt loam	6.347	1.4575	0.45	0.45	5.3	0.033	0.340	0.264
Cleveland, OH	14820	Silt loam	5.889	1.4575	0.45	0.45	5.3	0.017	0.406	0.579
Columbia, SC	13883	Sand	5.237	1.5105	0.43	29.7	4.05	0.006	0.127	0.802
Columbus, OH	14821	Silt loam	6.226	1.4575	0.45	0.45	5.3	0.018	0.376	0.560
Des Moines, IA	14933	Silty clay loam	6.492	1.5105	0.43	0.07	7.75	0.026	0.299	0.930
Detroit, MI	94847	Loamy sand	6.458	1.5635	0.41	14.59	4.38	0.027	0.195	0.117
Fort Worth, TX	03927	Clay	7.886	1.643	0.38	0.2	11.4	0.013	0.323	0.426
Grand Rapids, MI	94860	Loam	6.398	1.5105	0.43	1.04	5.39	0.040	0.261	0.520
Green Bay, WI	14898	Loam	6.626	1.5105	0.43	1.04	5.39	0.048	0.334	0.479
Greensboro, NC	13723	Sandy loam	5.657	1.5635	0.41	4.42	4.9	0.006	0.273	1.046
Greenville, SC	03870	Sandy loam	5.503	1.5635	0.41	4.42	4.9	0.005	0.270	1.433
Hartford, CT	14740	Sandy loam	5.214	1.5635	0.41	4.42	4.9	0.069	0.268	1.228
Houston, TX	12960	Sandy loam	5.837	1.5635	0.41	4.42	4.9	0.007	0.321	0.084
Huntington, WV	03860	Silt loam	5.172	1.4575	0.45	0.45	5.3	0.012	0.375	5.687
Huntsville, AL	03856	Silt loam	5.208	1.4575	0.45	0.45	5.3	0.009	0.351	0.474
Indianapolis, IN	93819	Silt loam	6.423	1.4575	0.45	0.45	5.3	0.018	0.368	0.445
Jackson, MS	03940	Silt loam	5.272	1.4575	0.45	0.45	5.3	0.008	0.438	0.745
Lexington, KY	93820	Silt loam	6.305	1.4575	0.45	0.45	5.3	0.018	0.338	2.150
Little Rock, AR	13963	Silt loam	5.405	1.4575	0.45	0.45	5.3	0.011	0.405	0.192
Los Angeles, CA	23174	Loamy sand	6.819	1.5635	0.41	14.59	4.38	0.008	0.310	0.302
Memphis, TN	13893	Silt loam	5.380	1.4575	0.45	0.45	5.3	0.008	0.455	1.369
Miami, FL	12839	Loamy sand	7.858	1.5635	0.41	14.59	4.38	0.012	0.116	0.136
Minneapolis, MN	14922	Silt loam	6.372	1.4575	0.45	0.45	5.3	0.023	0.275	0.686
Nashville, TN	13897	Silt loam	5.701	1.4575	0.45	0.45	5.3	0.011	0.354	1.665
New Orleans, LA	12916	Clay	6.391	1.643	0.38	0.2	11.4	0.082	0.346	0.073
New York, NY	94728	Loamy sand	5.267	1.5635	0.41	14.59	4.38	0.019	0.312	0.463

Table I.2-2. Site-Specific Surface Soil Parameters

City	Met Station ID	Soil Texture	pH	Dry Bulk Density (g/cm³)	Saturated Water Content (mL/cm³)	Saturated Hydraulic Conductivity (cm/yr)	Soil Moisture Coefficient (unitless)	Fraction Organic Carbon (unitless)	USLE Erodibility Factor (ton/acre)	USLE Length-Slope Factor (unitless)
Newark, NJ	14734	Loamy sand	5.234	1.5635	0.41	14.59	4.38	0.018	0.327	0.554
Norfolk, VA	13737	Sandy loam	4.730	1.5635	0.41	4.42	4.9	0.013	0.255	0.159
Oklahoma City, OK	13967	Silt loam	6.633	1.4575	0.45	0.45	5.3	0.011	0.423	0.528
Philadelphia, PA	13739	Silt loam	5.252	1.4575	0.45	0.45	5.3	0.013	0.352	1.094
Phoenix, AZ	23183	Loam	8.007	1.5105	0.43	1.04	5.39	0.003	0.300	0.263
Pittsburgh, PA	94823	Silt loam	5.158	1.4575	0.45	0.45	5.3	0.014	0.366	2.924
Portland, OR	24229	Silt loam	5.716	1.4575	0.45	0.45	5.3	0.023	0.343	1.199
Providence, RI	14765	Sandy loam	5.177	1.5635	0.41	4.42	4.9	0.077	0.270	1.050
Reno, NV	23185	Sandy loam	6.650	1.5635	0.41	4.42	4.9	0.012	0.304	3.206
Richmond, VA	13740	Sandy loam	4.949	1.5635	0.41	4.42	4.9	0.008	0.236	1.295
Roanoke, VA	13741	Loam	5.053	1.5105	0.43	1.04	5.39	0.009	0.250	2.492
Rockford, IL	94822	Silt loam	6.326	1.4575	0.45	0.45	5.3	0.020	0.310	0.532
San Francisco, CA	23234	Loam	6.242	1.5105	0.43	1.04	5.39	0.015	0.355	10.522
Seattle, WA	24233	Sandy loam	5.786	1.5635	0.41	4.42	4.9	0.032	0.288	2.165
South Bend, IN	14848	Loam	6.440	1.5105	0.43	1.04	5.39	0.017	0.317	0.489
St. Louis, MO	13994	Silt loam	6.180	1.4575	0.45	0.45	5.3	0.009	0.368	1.159
Tampa, FL	12842	Sand	5.403	1.5105	0.43	29.7	4.05	0.020	0.103	0.230
Wichita, KS	03928	Silt loam	6.768	1.4575	0.45	0.45	5.3	0.011	0.359	0.189

Table I.2-3. Site-Specific Subsurface Soil Parameters

City	Met Station ID	Soil Texture	Fraction Organic Carbon (mass fraction)	Soil Moisture Coefficient b (unitless)	Soil Retention Parameter alpha	Soil Retention Parameter beta	Saturated Hydraulic Conductivity (cm/h)	Residual Water Content (L/L)	Saturated Water Content (L/L)	Average Vadose Zone pH	Percent Organic Matter	Bulk Density of Soil	Average Aquifer Temp-erature (Celcius)
Albany, NY	14735	Silt loam	0.005	5.3	0.02	1.41	0.45	0.45	0.067	5.983	0.832	1.4575	9
Atlanta, GA	13874	Sandy loam	0.001	4.9	0.075	1.89	4.42	0.41	0.065	5.150	0.230	1.5635	18
Baltimore, MD	93721	Silt loam	0.003	5.3	0.02	1.41	0.45	0.45	0.067	5.496	0.552	1.4575	13
Boston, MA	14739	Loamy sand	0.004	4.38	0.124	2.28	14.59	0.41	0.057	5.112	0.727	1.5635	11
Boulder, CO	94018	Sandy loam	0.004	4.9	0.075	1.89	4.42	0.41	0.065	6.453	0.679	1.5635	9
Chicago, IL	94846	Loamy sand	0.012	4.38	0.124	2.28	14.59	0.41	0.057	6.855	2.140	1.5635	12
Cleveland, OH	14820	Silty clay loam	0.003	7.75	0.01	1.23	0.07	0.43	0.089	6.474	0.444	1.5105	12
Columbia, SC	13883	Sand	0.003	4.05	0.145	2.68	29.7	0.43	0.045	5.124	0.475	1.5105	18
Columbus, OH	14821	Silty clay loam	0.004	7.75	0.01	1.23	0.07	0.43	0.089	6.881	0.743	1.5105	13
Des Moines, IA	14933	Silty clay loam	0.010	7.75	0.01	1.23	0.07	0.43	0.089	6.188	1.718	1.5105	12
Detroit, MI	94847	Clay loam	0.004	8.52	0.019	1.31	0.26	0.41	0.095	7.020	0.642	1.5635	11
Fort Worth, TX	03927	Clay	0.007	11.4	0.008	1.09	0.2	0.38	0.068	7.963	1.161	1.643	20
Grand Rapids, MI	94860	Loam	0.022	5.39	0.036	1.56	1.04	0.43	0.078	6.915	3.754	1.5105	10
Green Bay, WI	14898	Silty clay loam	0.022	7.75	0.01	1.23	0.07	0.43	0.089	7.290	3.789	1.5105	9
Greensboro, NC	13723	Loamy sand	0.001	4.38	0.124	2.28	14.59	0.41	0.057	5.825	0.214	1.5635	16
Greenville, SC	03870	Clay	0.001	11.4	0.008	1.09	0.2	0.38	0.068	5.300	0.247	1.643	17
Hartford, CT	14740	Sandy loam	0.012	4.9	0.075	1.89	4.42	0.41	0.065	5.316	2.137	1.5635	11
Houston, TX	12960	Clay	0.006	11.4	0.008	1.09	0.2	0.38	0.068	6.555	0.973	1.643	24
Huntington, WV	03860	Silty clay	0.003	10.4	0.005	1.09	0.02	0.36	0.07	5.385	0.456	1.696	14
Huntsville, AL	03856	Clay	0.001	11.4	0.008	1.09	0.2	0.38	0.068	5.280	0.237	1.643	17
Indianapolis, IN	93819	Loam	0.007	5.39	0.036	1.56	1.04	0.43	0.078	7.021	1.164	1.5105	13
Jackson, MS	03940	Silt loam	0.001	5.3	0.02	1.41	0.45	0.45	0.067	5.437	0.157	1.4575	19
Lexington, KY	93820	Silty clay	0.004	10.4	0.005	1.09	0.02	0.36	0.07	6.393	0.765	1.696	14
Little Rock, AR	13963	Loam	0.004	5.39	0.036	1.56	1.04	0.43	0.078	5.744	0.638	1.5105	18
Los Angeles, CA	23174	Loamy sand	0.001	4.38	0.124	2.28	14.59	0.41	0.057	7.084	0.200	1.5635	20
Memphis, TN	13893	Silt loam	0.001	5.3	0.02	1.41	0.45	0.45	0.067	5.397	0.229	1.4575	17
Miami, FL	12839	Loamy sand	0.002	4.38	0.124	2.28	14.59	0.41	0.057	7.744	0.300	1.5635	26
Minneapolis, MN	14922	Silt loam	0.007	5.3	0.02	1.41	0.45	0.45	0.067	6.600	1.275	1.4575	8
Nashville, TN	13897	Clay	0.003	11.4	0.008	1.09	0.2	0.38	0.068	5.789	0.587	1.643	16
New Orleans, LA	12916	Clay	0.033	11.4	0.008	1.09	0.2	0.38	0.068	7.026	5.820	1.643	22

Table I.2-3. Site-Specific Subsurface Soil Parameters

City	Met Station ID	Soil Texture	Fraction Organic Carbon (mass fraction)	Soil Moisture Coefficient b (unitless)	Soil Retention Parameter alpha	Soil Retention Parameter beta	Saturated Hydraulic Conductivity (cm/h)	Residual Water Content (L/L)	Saturated Water Content (L/L)	Average Vadose Zone pH	Percent Organic Matter	Bulk Density of Soil	Average Aquifer Temp-erature (Celcius)
New York, NY	94728	Loamy sand	0.002	4.38	0.124	2.28	14.59	0.41	0.057	5.619	0.276	1.5635	12
Newark, NJ	14734	Loamy sand	0.002	4.38	0.124	2.28	14.59	0.41	0.057	5.738	0.318	1.5635	12
Norfolk, VA	13737	Clay	0.004	11.4	0.008	1.09	0.2	0.38	0.068	4.719	0.693	1.643	16
Oklahoma City, OK	13967	Sandy loam	0.004	4.9	0.075	1.89	4.42	0.41	0.065	6.486	0.694	1.5635	17
Philadelphia, PA	13739	Silt loam	0.006	5.3	0.02	1.41	0.45	0.45	0.067	5.413	1.106	1.4575	12
Phoenix, AZ	23183	Loam	0.001	5.39	0.036	1.56	1.04	0.43	0.078	8.049	0.254	1.5105	22
Pittsburgh, PA	94823	Silt loam	0.003	5.3	0.02	1.41	0.45	0.45	0.067	5.508	0.455	1.4575	11
Portland, OR	24229	Silt loam	0.006	5.3	0.02	1.41	0.45	0.45	0.067	5.699	1.093	1.4575	12
Providence, RI	14765	Sandy loam	0.012	4.9	0.075	1.89	4.42	0.41	0.065	5.224	2.006	1.5635	12
Reno, NV	23185	Sandy loam	0.003	4.9	0.075	1.89	4.42	0.41	0.065	6.615	0.599	1.5635	14
Richmond, VA	13740	Sandy clay loam	0.003	7.12	0.059	1.48	1.31	0.39	0.1	4.848	0.484	1.6165	15
Roanoke, VA	13741	Clay	0.002	11.4	0.008	1.09	0.2	0.38	0.068	5.439	0.320	1.643	15
Rockford, IL	94822	Silty clay loam	0.006	7.75	0.01	1.23	0.07	0.43	0.089	6.309	1.119	1.5105	12
San Francisco, CA	23234	Loam	0.005	5.39	0.036	1.56	1.04	0.43	0.078	6.276	0.822	1.5105	17
Seattle, WA	24233	Loam	0.009	5.39	0.036	1.56	1.04	0.43	0.078	5.923	1.518	1.5105	11
South Bend, IN	14848	Sand	0.004	4.05	0.145	2.68	29.7	0.43	0.045	6.269	0.771	1.5105	12
St. Louis, MO	13994	Silty clay loam	0.005	7.75	0.01	1.23	0.07	0.43	0.089	6.335	0.876	1.5105	14
Tampa, FL	12842	Sand	0.004	4.05	0.145	2.68	29.7	0.43	0.045	5.452	0.695	1.5105	24
Wichita, KS	03928	Silty clay	0.007	10.4	0.005	1.09	0.02	0.36	0.07	7.364	1.232	1.696	16

Table I.2-4. Site-Specific Inputs to General Soil Column Model

City	Met Station ID	SCS Curve Number (unitless)	Depth to Root Zone (cm)	Soil Moisture Field Capacity (volume %)	Soil Moisture Wilting Point (volume %)
Albany, NY	14735	77.73	154.66	22.475	11.475
Atlanta, GA	13874	67.84	173.57	18.525	8.825
Baltimore, MD	93721	79.50	156.28	22.475	11.475
Boston, MA	14739	69.29	178.99	18.525	8.825
Boulder, CO	94018	77.27	147.09	22.475	11.475
Chicago, IL	94846	75.53	154.24	18.525	8.825
Cleveland, OH	14820	85.19	98.60	25.125	15.55
Columbia, SC	13883	43.96	206.84	7.3	2.35
Columbus, OH	14821	80.79	87.34	22.475	11.475
Des Moines, IA	14933	71.62	87.44	18.525	8.825
Detroit, MI	94847	81.38	94.00	22.475	11.475
Fort Worth, TX	03927	85.27	63.98	25.125	15.55
Grand Rapids, MI	94860	70.69	120.07	18.525	8.825
Green Bay, WI	14898	79.84	90.67	22.475	11.475
Greensboro, NC	13723	67.62	157.57	18.525	8.825
Greenville, SC	03870	67.54	82.54	18.525	8.825
Hartford, CT	14740	77.67	171.80	22.475	11.475
Houston, TX	12960	83.37	85.27	25.125	15.55
Huntington, WV	03860	80.31	106.82	25.125	15.55
Huntsville, AL	03856	68.94	68.95	18.525	8.825
Indianapolis, IN	93819	72.42	116.23	18.525	8.825
Jackson, MS	03940	76.52	159.00	22.475	11.475
Lexington, KY	93820	79.82	57.16	22.475	11.475
Little Rock, AR	13963	67.07	154.87	18.525	8.825
Los Angeles, CA	23174	63.29	157.32	7.3	2.35
Memphis, TN	13893	70.07	136.42	18.525	8.825
Miami, FL	12839	73.98	145.41	18.525	8.825
Minneapolis, MN	14922	73.10	124.32	18.525	8.825
Nashville, TN	13897	78.31	80.09	22.475	11.475
New Orleans, LA	12916	87.07	90.42	25.125	15.55
New York, NY	94728	75.96	168.97	18.525	8.825
Newark, NJ	14734	75.70	170.20	18.525	8.825
Norfolk, VA	13737	85.18	81.01	25.125	15.55
Oklahoma City, OK	13967	71.75	117.15	18.525	8.825
Philadelphia, PA	13739	81.84	144.62	22.475	11.475
Phoenix, AZ	23183	66.75	123.61	18.525	8.825
Pittsburgh, PA	94823	78.31	157.80	22.475	11.475
Portland, OR	24229	78.46	155.90	22.475	11.475
Providence, RI	14765	76.17	183.35	22.475	11.475
Reno, NV	23185	70.89	130.86	22.475	11.475
Richmond, VA	13740	65.87	132.95	18.525	8.825
Roanoke, VA	13741	64.53	95.19	18.525	8.825
Rockford, IL	94822	71.92	85.44	18.525	8.825
San Francisco, CA	23234	80.35	151.05	22.475	11.475
Seattle, WA	24233	78.32	170.18	22.475	11.475
South Bend, IN	14848	71.51	103.23	18.525	8.825
St. Louis, MO	13994	72.30	101.18	18.525	8.825
Tampa, FL	12842	81.09	141.58	22.475	11.475
Wichita, KS	03928	85.23	52.72	25.125	15.55

Table I.2-5. Site-Specific Meteorological Parameters

City	Mean Annual Recharge (m/s)	Average Annual Runoff (cm/yr)	USLE Rainfall/ Erosivity Factor (1/yr)	Average Annual Recharge (cm/yr)	Average Air Temperature (degrees Celsius
Albany, NY	3.862	89.72	120	3.99E-04	8.68
Atlanta, GA	3.938	135	310	6.52E-04	16.38
Baltimore, MD	3.964	101.98	200	3.49E-04	12.7
Boston, MA	5.657	103.81	125	6.48E-04	10.35
Boulder, CO	3.783	37.66	50	9.62E-05	10.11
Chicago, IL	4.632	87.65	155	2.41E-04	9.69
Cleveland, OH	4.593	94.85	120	3.92E-04	9.91
Columbia, SC	3.1	125.94	250	1.04E-03	17.09
Columbus, OH	3.584	93.31	150	3.32E-04	11.24
Des Moines, IA	4.773	89.1	170	2.43E-04	10.65
Detroit, MI	4.744	79.36	115	3.24E-04	9.35
Fort Worth, TX	4.831	88.83	250	1.50E-04	18.55
Grand Rapids, MI	4.287	92.89	110	5.25E-04	8.79
Green Bay, WI	4.237	70.03	95	2.47E-04	6.86
Greensboro, NC	3.248	109.95	230	4.52E-04	14.91
Greenville, SC	4.831	88.83	300	8.37E-04	15.58
Hartford, CT	3.693	113.79	150	5.51E-04	9.92
Houston, TX	3.604	112.59	425	1.86E-04	20.04
Huntington, WV	2.961	106.37	140	2.20E-04	12.8
Huntsville, AL	3.618	140.72	280	1.02E-03	15.84
Indianapolis, IN	4.141	104.82	175	4.70E-04	11.2
Jackson, MS	3.232	148.77	390	4.99E-04	17.89
Lexington, KY	3.729	115.38	195	2.49E-04	12.78
Little Rock, AR	3.138	134.9	310	6.21E-04	16.55
Los Angeles, CA	3.592	25.25	60	1.83E-04	16.63
Memphis, TN	3.798	131.41	300	5.86E-04	16.82
Miami, FL	4.221	126.43	480	6.57E-04	24.31
Minneapolis, MN	4.766	73.66	140	1.71E-04	8.3
Nashville, TN	3.63	100.19	220	4.22E-04	15.61
New Orleans, LA	3.531	147.84	555	3.01E-04	20.11
New York, NY	5.252	112.88	185	1.15E-03	12.28
Newark, NJ	4.559	101.97	175	4.08E-04	12.4
Norfolk, VA	4.997	107.87	280	2.82E-04	15.75
Oklahoma City, OK	5.442	89.86	250	2.21E-04	15.52
Philadelphia, PA	4.188	105.03	185	3.50E-04	12.24
Phoenix, AZ	2.669	19.43	50	9.62E-05	23.34
Pittsburgh, PA	3.943	96.57	125	3.51E-04	10.27
Portland, OR	3.64	87.7	40	8.52E-04	11.81
Providence, RI	4.691	115.05	155	5.21E-04	10.63
Reno, NV	3.232	17.74	35	1.05E-04	11.44
Richmond, VA	3.55	104.53	210	4.80E-04	14.38
Roanoke, VA	3.451	103.74	150	5.67E-04	13.35
Rockford, IL	4.542	91.59	160	3.90E-04	9.11
San Francisco, CA	4.849	46.08	50	2.09E-04	13.26
Seattle, WA	3.859	91.99	35	9.83E-04	11
South Bend, IN	4.519	98.32	160	5.22E-04	9.92
St. Louis, MO	4.466	100.76	220	3.56E-04	13.16
Tampa, FL	3.753	110.86	445	3.31E-04	22.12
Wichita, KS	5.362	76.95	200	1.27E-04	13.49

Section I.3

Characterization of Aquifer Types for Each Site

Table I.3-1. Hydrogeologic Data for Locations Modeled in Paints

MetSta	City	State	Heath Hydrogeologic Region	Aquifer Type	Assigned hgdb hydrogeologic environments		Fraction
03856	Huntsville	AL	Nonglaciated Central	Limestone and dolomite	12	Solution limestone	1.00
13963	Little Rock	AR	Atlantic & Gulf Coastal Plain	Tertiary surficial aquifer	10	Unconsol. & semiconsol. shallow aquifers	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
23183	Phoenix	AZ	Alluvial Basins	Alluvial aquifers	5	Alluvial basins, valleys, and fans	1.00
23174	Los Angeles	CA	Alluvial Basins	Alluvium and older sediments	5	Alluvial basins, valleys, and fans	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
23234	San Francisco	CA	Alluvial Basins	Alluvium and older sediments	5	Alluvial basins, valleys, and fans	1.00
94018	Boulder	CO	Nonglaciated Central	Sandstone, conglomerate, shale, siltstone	2	Bedded sedimentary rock	1.00
14740	Hartford	CT	Glaciated Central	Sandstone, shale, siltstone	2	Bedded sedimentary rock	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
12839	Miami	FL	Southeast Coastal Plain	Limestone, sandstone, and sand	12	Solution limestone	0.50
				Coastal deposits	4	Sand and gravel	0.50
12842	Tampa	FL	Southeast Coastal Plain	Limestone and dolomite	12	Solution limestone	0.50
				Coastal deposits	4	Sand and gravel	0.50
13874	Atlanta	GA	Piedmont & Blue Ridge	Granite, gneiss, schist, quartzite	1	Metamorphic and igneous	1.00

(continued)

Table I.3-1. (continued)

MetSta	City	State	Heath Hydrogeologic Region	Aquifer Type	Assigned hgdb hydrogeologic environments		Fraction
14933	Des Moines	IA	Glaciated Central	Dolomite and sandstone	2	Bedded sedimentary rock	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
94846	Chicago	IL	Glaciated Central	Dolomite, fractured, silty at base	12	Solution limestone	1.00
94822	Rockford	IL	Glaciated Central	Sandstone, dolomite	2	Bedded sedimentary rock	0.33
				Till over sandstone, dolomite	3	Till over sedimentary rock	0.33
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.17
					7	River valleys without overbank deposits	0.17
93819	Indianapolis	IN	Glaciated Central	Sand and gravel lenses in till	9	Till and till over outwash	0.33
				Till over sandstone/limestone/shale	3	Till over sedimentary rock	0.33
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.17
					7	River valleys without overbank deposits	0.17
14848	South Bend	IN	Glaciated Central	Glacial outwash aquifer	8	Outwash	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
03928	Wichita	KS	Alluvial Valleys	Quaternary fluvial deposits	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
			High Plains	Un./Semiconsol. Shallow Aq.	5	Alluvial basins, valleys, and fans	0.50
93820	Lexington	KY	Nonglaciated Central	Limestone/shale aquifers	12	Solution limestone	1.00

(continued)

Table I.3-1. (continued)

MetSta	City	State	Heath Hydrogeologic Region	Aquifer Type	Assigned hgdb hydrogeologic environments		Fraction
12916	New Orleans	LA	Atlantic & Gulf Coastal Plain	Pleistocene aquifers	4	Sand and gravel	0.50
				Tertiary surficial aquifer	10	Unconsol. & semiconsol. shallow aquifers	0.50
14739	Boston	MA	Northeast & Superior Uplands	Crystalline bedrock aquifers	1	Metamorphic and igneous	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
93721	Baltimore	MD	Piedmont & Blue Ridge	Crystalline bedrock aquifers	1	Metamorphic and igneous	0.50
			Atlantic & Gulf Coastal Plain	Aquifers in Potomac group	10	Unconsol. & semiconsol. shallow aquifers	0.50
94847	Detroit	MI	Glaciated Central	Outwash, glaciofluvial deposits, till	8	Outwash	0.33
				Limestone and dolomite	12	Solution limestone	0.33
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.17
					7	River valleys without overbank deposits	0.17
94860	Grand Rapids	MI	Glaciated Central	Outwash, glaciofluvial deposits, till	8	Outwash	0.33
				Sandstone/limestone/shale	2	Bedded sedimentary rock	0.33
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.17
					7	River valleys without overbank deposits	0.17
14922	Minneapolis	MN	Glaciated Central	Sandstone and dolomite	2	Bedded sedimentary rock	0.50
				Till over sandstone and dolomite	3	Till over sedimentary rock	0.50
13994	St. Louis	MO	Glaciated Central	Glacial drift	9	Till and till over outwash	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25

(continued)

Table I.3-1. (continued)

MetSta	City	State	Heath Hydrogeologic Region	Aquifer Type	Assigned hgdb hydrogeologic environments		Fraction
03940	Jackson	MS	Atlantic & Gulf Coastal Plain	Oligocene surficial aquifer	10	Unconsol. & semiconsol. shallow aquifers	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
13723	Greensboro	NC	Piedmont & Blue Ridge	Crystalline rock aquifers	1	Metamorphic and igneous	1.00
14734	Newark	NJ	Glaciated Central	Shale and sandstone aquifer	3	Till over sedimentary rock	0.50
				Till or ground moraine	9	Till and till over outwash	0.50
23185	Reno	NV	Alluvial Basins	Basin fill aquifer	5	Alluvial basins, valleys, and fans	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
14735	Albany	NY	Glaciated Central	Till over sandstone/shale/limestone	3	Till over sedimentary rock	0.33
				Lacustrine & ice-contact deposits	8	Outwash	0.33
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.17
					7	River valleys without overbank deposits	0.17
94728	New York	NY	Glaciated Central	Till over sandstone/shale	3	Till over sedimentary rock	0.50
				Till or ground moraine	9	Till and till over outwash	0.50
14820	Cleveland	OH	Glaciated Central	Shale/sandy shale/sandstone	3	Till over sedimentary rock	1.00
14821	Columbus	OH	Glaciated Central	Glaciofluvial outwash	8	Outwash	0.33
				Limestone and dolomite	12	Solution limestone	0.33
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.17
					7	River valleys without overbank deposits	0.17

(continued)

Table I.3-1. (continued)

MetSta	City	State	Heath Hydrogeologic Region	Aquifer Type	Assigned hgdb hydrogeologic environments		Fraction
13967	Oklahoma City	OK	Nonglaciated Central	Sandstone/siltstone/shale	2	Bedded sedimentary rock	0.50
			Alluvial Valleys	Stream alluvium/terrace deposits	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
24229	Portland	OR	Alluvial Basins	Basin fill and alluvial aquifers	5	Alluvial basins, valleys, and fans	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
13739	Philadelphia	PA	Piedmont & Blue Ridge	Fractured igneous/metamorphic	1	Metamorphic and igneous	0.50
			Nonglaciated Central	Fractured sandstone and shale	2	Bedded sedimentary rock	0.50
94823	Pittsburgh	PA	Nonglaciated Central	Fractured sandstone and shale	2	Bedded sedimentary rock	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
14765	Providence	RI	Glaciated Central	Stratified drift	8	Outwash	0.50
				Till over stratified drift	9	Till and till over outwash	0.50
13883	Columbia	SC	Atlantic & Gulf Coastal Plain	White and gray sand and gravel	10	Unconsol. & semiconsol. shallow aquifers	0.50
			Piedmont & Blue Ridge	Crystalline rock aquifers	1	Metamorphic and igneous	0.50
03870	Greenville	SC	Piedmont & Blue Ridge	Crystalline rock aquifers	1	Metamorphic and igneous	1.00
13893	Memphis	TN	Atlantic & Gulf Coastal Plain	Tertiary sand aquifers	10	Unconsol. & semiconsol. shallow aquifers	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25

(continued)

Table I.3-1. (continued)

MetSta	City	State	Heath Hydrogeologic Region	Aquifer Type	Assigned hgdb hydrogeologic environments		Fraction
13897	Nashville	TN	Nonglaciated Central	Ordovician carbonate aquifer	12	Solution limestone	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
03927	Fort Worth	TX	Nonglaciated Central	Sandstone/sand/conglomerate	2	Bedded sedimentary rock	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25
12960	Houston	TX	Atlantic & Gulf Coastal Plain	Interbedded sand, silt, clay	10	Unconsol. & semiconsol. shallow aquifers	1.00
13737	Norfolk	VA	Atlantic & Gulf Coastal Plain	Sand and gravel	10	Unconsol. & semiconsol. shallow aquifers	1.00
13740	Richmond	VA	Piedmont & Blue Ridge	Crystalline rock aquifers	1	Metamorphic and igneous	0.50
			Atlantic & Gulf Coastal Plain	Yorktown-Eastover Aquifer	10	Unconsol. & semiconsol. shallow aquifers	0.50
13741	Roanoke	VA	Piedmont & Blue Ridge	Crystalline rock aquifers	1	Metamorphic and igneous	0.50
			Nonglaciated Central	Ridge and valley aquifers	12	Solution limestone	0.50
24233	Seattle	WA	Alluvial Basins	Glacial drift aquifer	8	Outwash	0.50
				Alluvial basin	5	Alluvial basins, valleys, and fans	0.50
14898	Green Bay	WI	Glaciated Central	Till or drift over sandstone	3	Till over sedimentary rock	0.50
				Outwash over sandstone	2	Bedded sedimentary rock	0.50
03860	Huntington	WV	Nonglaciated Central	Shale with sandstone	2	Bedded sedimentary rock	0.50
			Alluvial Valleys	Alluvial valley aquifers	6	River valleys with overbank deposits	0.25
					7	River valleys without overbank deposits	0.25

Section I.4

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Appendix J

Statistical Sampling Procedures for Selection of Waste Management Units

Appendix J

Statistical Sampling Procedures for Selection of Waste Management Units

This appendix provides a description of the sampling procedures used in this analysis. Sampling procedures were used to

- Replicate the 49 meteorological stations to produce the 10,000-record set of locations used in the probabilistic analysis
- Select 200 treatment tank and 200 surface impoundment units from the treatment storage and disposal facilities (TSDF) and Industrial D databases, respectively
- Replicate the 68 landfill units, 200 treatment tank units, and 200 surface impoundment units to produce three 10,000-record data sets, one for each waste management unit type evaluated in the probabilistic analysis
- Assign surface area bins or strata to the landfill and surface impoundment units and to assign surface area-height bins to treatment tank units for use in air dispersion modeling.

Also included in this appendix are descriptions of the PPS-systematic and Dalenius-Hodges stratification algorithms used for the above-listed tasks.

J.1 Replication of 49 Meteorological Locations

The meteorological locations were replicated to a total of 10,000 records for the Monte Carlo analysis using a PPS-systematic sampling scheme with the weights described in Section 4.0. A description of the algorithm to perform PPS-systematic sampling is discussed below. It should be noted that, initially, a 20,000-record data set of locations was produced using the procedure described in this appendix, and, subsequently, the data set was reduced to 10,000 records for use in the probabilistic analysis. The 10,000-record data set was compiled by selecting the first 10,000 records from a randomly sorted set of the 20,000 records.

J.2 Sampling of Treatment Tank and Surface Impoundment Units

For the surface impoundments, it was necessary to produce 10,000 records from the total 1,903 surface impoundments for the Monte Carlo analysis. Because of the complexity that would have been required to carry out the modeling steps on all 1,903 surface impoundments, it was decided to subsample the surface impoundments in the Industrial D Survey database to select 200 units for use in the probabilistic analysis. That is, rather than selecting 10,000 units directly from the Industrial D database, which would have required characterizing and modeling over 1,000 individual units, first subsampling from the database and then replicating the subsample to 10,000 records allowed the modeling to be based on a smaller number of individual units. It was required, therefore, that the subsampling be done in such way as to preserve, to the extent possible, the range and distribution of the surface impoundments in the original database. For the same reasons, the TSDF data set of 893 treatment tanks was also subsampled to select the 200 treatment tank units used in the probabilistic analysis. It should be noted that initially 20,000-record data sets of treatment tank and surface impoundment units were produced using the procedure described in this appendix; subsequently, these data sets were reduced to 10,000-record data sets for use in the probabilistic analysis. The 10,000-record data set was compiled by selecting the first 10,000 records from a randomly sorted set of the 20,000 records. The following sampling procedures were applied to both the treatment tank and surface impoundment data sets.

J.2.1 Selection of Subsample

For surface impoundments, Industrial D data were divided into six strata using the Dalenius-Hodges procedure (Cochran, 1963) based on the surface areas (square meters) of the units. The Dalenius-Hodges procedure sorts the data by the area and uses the cumulative distribution of the areas to determine the cutoffs for each stratum. The optimal selection of sample members when using the Dalenius-Hodges definition of strata is to select equal sample sizes from each stratum. Due to the skewed nature of the distribution of the surface areas in the data set, a very small percentage of the units in the original database are contained in the three strata with the largest areas. Therefore, all units in the three strata containing the largest areas were selected to be in the sample. The remaining units needed to obtain a sample of 200 members were equally allocated among the other three strata. After sorting the data set by area, a systematic sample selection procedure was used to select the sample units independently from each of the three strata with the smaller areas. Sorting the data set by the surface area before performing a systematic sample selection procedure preserves the range of the areas that appear in the sample. This same procedure was used for both surface impoundments and treatment tanks; for treatment tanks, however, the strata were constructed from the TSDF data using both surface area and height data.

J.2.2 Replication to Monte Carlo Iterations

It was important that the distribution of the Monte Carlo iterations be as close as possible to the distribution of the units in the original data set. This was achieved by weighting each of the 200 sample units according to the stratum in which the unit was selected. For example, if 10 units were selected from a stratum containing 1,000 units, each of the 10 selected units "represents" 100 of the units from that stratum that were not selected. Because all of the units in the three strata with the larger areas were selected to be in the sample, each of these units with the largest areas "represented" only themselves and were assigned a weight equal to 1. When the replication of the 200 sample units to 20,000 records (later reduced to 10,000) was performed, the weights determined how many replicates of each unit were produced from a PPS-systematic sampling scheme. For example, a unit with a weight of 100 would have twice as many replicates in the Monte Carlo data set as a unit with a weight of 50. The resulting distribution of the 20,000 Monte Carlo iterations is close to the distribution of what the Monte Carlo iterations would have been if the original data set of all the units was replicated directly to total 20,000 without subsampling the data set to 200 units.

J.3 Assignment of Bins

To reduce the amount of resources needed for the time-consuming runs of the air modeling program, the 68 landfills and 200 selected surface impoundments were assigned to 21 and 20 surface area strata, respectively, and the median surface area for each stratum was used as input for the air modeling. As an alternative to visually checking the data, the Dalenius-Hodges procedure was used on the natural log of the area to assign the strata. Applying the natural log to the area values reduced the skewness of the distributions and allowed more strata to be assigned to the lower end of the distributions, where changes in the surface area had the largest effect on the air modeling results. That is, more data points were desired and were assigned to the units with the smaller areas. For the tanks, the Dalenius-Hodges procedure was used on the natural log of the areas on the 200 selected tanks to determine 10 strata. The tanks were also divided into three height categories to produce a total of 31 strata containing at least one of the 200 tanks selected to be in the subsample (some of the area-height combinations contain no units). The medians for each of the 31 strata were used to perform the air modeling on the tanks. The Dalenius-Hodges procedure for determining strata is described in the next section.

J.4 Sampling Algorithms

Two sampling procedures were used in this analysis: PPS-systematic and Dalenius-Hodges stratification. Each is described below.

J.4.1 PPS-Systematic

In PPS-systematic, each record is assigned a size measure, or weight. As illustrated in Figure J-1, imagine that all of the records in the data set are lined up along a ruler and the space that each record occupies on the ruler is determined by the size measure. The size measures are summed for the data set and the skip interval is calculated as the total of the size measures divided by the number of records to select. A random number from 0 to the value of the skip interval is generated as the starting position. The algorithm jumps to the value equal to the starting position plus the skip interval. The record that takes up the space on the ruler where the jump lands is the first record selected to be in the sample. The algorithm continues to jump along the ruler until the desired number of records have been selected. Implicit stratification can be used by sorting the data set by a variable of interest before running the sample selection

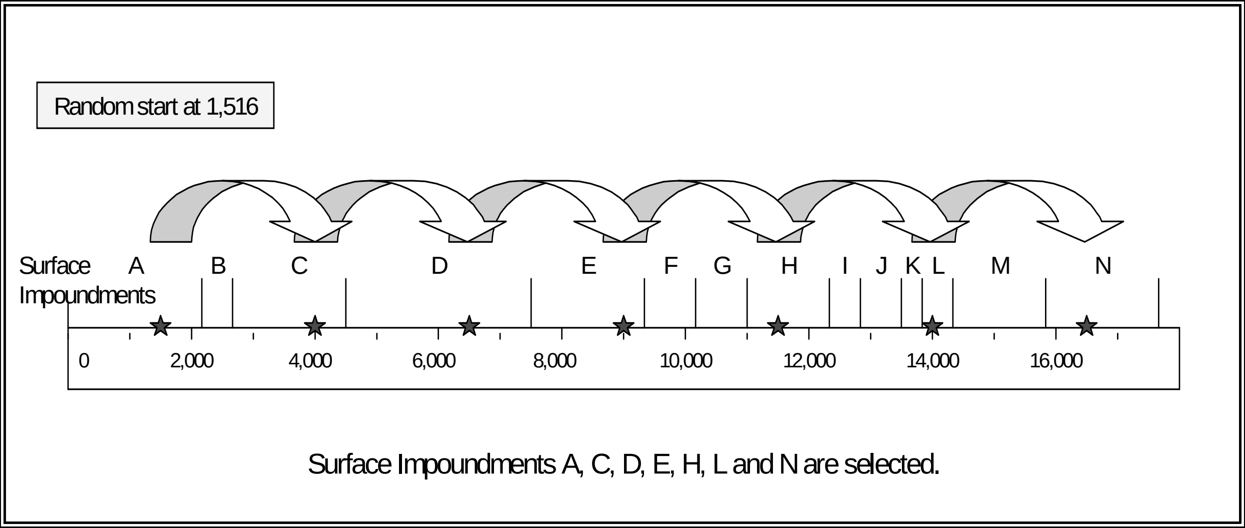

Figure J-1. Illustration of the PPS-systematic sampling procedure.

algorithm. For explicit stratification, this procedure would be performed within each stratum so that the desired number of records to be selected from each stratum would be preserved.

J.4.2 Dalenius-Hodges Stratification

The method for determining strata proposed by Dalenius and Hodges uses the cumulative distribution of the variable of interest. The distribution of the variable is divided into no more than 100 intervals. For each interval, the square root of the number of records in the interval is first calculated, then sum of the square roots is calculated for each interval. For example, the first interval has the value of the square root of the number of records in that interval; the second interval is the sum of the square root for the first interval plus the square root of the number of records in the second interval. This process continues until the last interval is the cumulative sum of the square roots. The last cumulative sum is divided by the number of strata desired and multiplied by 1, 2, 3, ... to the total number of strata. The cutoff for the first stratum would be the interval for which the cumulative sum of the square roots falls closest to the quotient. The cutoff for the second stratum would be the interval for which the cumulative sum is closest to the quotient multiplied by 2. This process continues until all of the strata have been determined.

Reference

Cochran, William G. 1963. *Sampling Techniques, 2nd Edition*. New York, NY: John Wiley and Sons, Inc.

Appendix K

Modifications to HWIR Source Partition Model Programs

Appendix K

Modifications to HWIR Source Partition Model Programs

The source partition models for landfills, treatment tanks, and surface impoundments were developed for HWIR99 (U.S. EPA, 1999). The HWIR models were originally developed to operate within a larger modeling system, which is described in *Overview of the FRAMES - HWIR Technology Software System* (PNNL, 1999). A few basic changes were made to allow the model to run as a stand-alone model. These changes are described below.

K.1 Tanks and Surface Impoundments

The HWIR99 tank and surface impoundment model was used to model environmental releases from both treatment tanks and surface impoundments. The only difference is that, for treatment tanks, the bottom of the unit was assumed to be impervious so no leachate was formed. The changes described in this section, therefore, are applicable to both treatment tank and surface impoundment modeling conducted for the paints listing analysis.

K.1.1 Temperature Correction

The temperature correction routines were revised so that they were performed internal to the program rather than through calls to the dynamic link library (dll) routines developed by Pacific Northwest Laboratories for the HWIR project. This change was made because the data sets for the dll temperature correction routines for HWIR did not include all the chemicals of interest for the paints listing project. Routines for temperature corrections were instated for chemical diffusivity in air (D_a), chemical diffusivity in water (D_w), and Henry's law constant (H). The correction routine for D_a was derived from the FSG Method (Lyman, 1990, Ch. 17, Equation 17-12), and the routine for D_w was derived from Equation 17-24 (Hayduk and Laudie) in Lyman et al. (1990). The temperature correction for H used estimates of the heat of vaporization from Lyman et al. (1990, Equation 13-21). The Haggenmacher method (Lyman et al., 1990, Section 13-5) is used to get the heat of vaporization at the boiling point. Temperature corrections for partitioning (K_d, K_{oc}), hydrolysis, and solubility were not included in the paints listing model although they were included for HWIR.

The temperature correction routines introduced several new input variables to the model: Antoine's constants B and C, the boiling temperature of the chemical, and the critical temperature and pressure for the chemical. Changes were made to the program executables and data dictionary files to read these data into the program.

K.1.2 Quiescent Tanks and Impoundments

In the HWIR module code, quiescent tanks and impoundments (i.e., where the fraction of the surface that is aerated, F_{aer}, is zero) cause a division by zero in the calculations. To prevent this from happening, the program was set up to call an error condition if F_{aer} is zero. For the paints listing project, the program was modified so that F_{aer} can be set to zero without causing a division by zero problem. The error call was also commented out.

K.2 Landfill Model

The HWIR99 model was used in the paints listing risk assessment to model environmental releases from industrial landfills. The changes described in this section are applicable to industrial landfill modeling conducted for the paints listing analysis.

K.2.1 Temperature Correction

Changes to the temperature correction routines for the landfill models were implemented in a manner similar to that described for tanks and surface impoundments.

K.2.2 Soil Column Model

A few sites were generating warning/error messages regarding the leachate contaminant flux processing routine for the landfill cell simulation, which is called on when the time between convective events in the landfill waste is greater than 1 year (see Section 5.1). The warnings indicated errors in the leachate contaminant flux output for the landfill as a whole. In response, some changes were made to the landfill model (file: landfill.cpp) to correct the problems. It was determined that the warning messages were occurring in two cases.

The first case was for a mercury site where a check of internal calculations revealed that the advective time step (time required for the contaminant to travel across one computational cell in the waste) was equal to the length of the simulation (200 years). Because an advective time step of this length was not originally anticipated in the program's design, two internal variables were not being initialized and updated properly for this condition. This was corrected.

The second case generating warning messages involved simulations of perchloroethylene in certain landfills. Here the problem involved the inability of the leachate contaminant flux processing routine to properly handle the case where the computational time step in the first year of the landfill cell simulation was much greater than the time step in subsequent years. To speed processing time, the program is designed to determine a time step that is large enough to allow the program to run quickly, yet small enough to account properly for important time-dependent processes. Originally this time step was determined based on the minimum of the time required for a chemical to travel across a computational element within a waste layer and half of the time required to lay down a new layer of waste. The time step was changed to be based on the minimum of these two times and the time required for chemical transport in the cover soil. This change led to a smaller time step in the first year of the simulation, thereby reducing the disparity between the time step in the first year of the simulation and in subsequent years for the perchloroethylene case.

K.2.3 Memory Management and System Performance

A “memory leak” in the landfill module was found and eliminated when it was discovered that the performance of the program slowed substantially over the course of several thousand runs. In addition, some of the Windows interface components were disabled to speed operation of the program.

K.2.4 Erosion/Runoff Module

An error was discovered in the erosion/runoff module relating to the moisture content properties. The module was designed to ensure that the soil moisture did not exceed the porosity and that the field capacity was less than the wilting point. However, the module did not properly account for the fact that the porosity is input as a fraction whereas the soil moisture wilting point and field capacities are input as percentages. This caused the program to frequently reset the values of these parameters internally and issue a warning message. The error was corrected and the warning messages did not reappear.

K.3 References

Lyman, W.J., W. F. Reehl, and D.H. Rosenblatt. 1990. *Handbook of Chemical Property Estimation Methods: Environmental Behavior of Organic Compounds*. American Chemical Society, Washington, D.C.

PNNL (Pacific Northwest National Laboratory). 1999. *Documentation for the FRAMES-HWIR Technology Software System. Volume 1: System Overview*. Prepared for the Office of Research and Development and Office of Solid Waste, U.S. Environmental Protection Agency, Washington, DC. Richland, WA.

U.S. EPA (Environmental Protection Agency). 1999. *Data Requirements and Confidence Indicators for Benchmarks Supporting Exemption Criteria for the Hazardous Waste Identification Rule (HWIR99).* Office of Solid Waste, Washington, DC. Located at http://www.epa.gov/epaoswer/hazwaste/id/hwirwste/risk.htm

Appendix L

Source Data

Table L-1 Landfill Source Model Inputs

Table L-2 Surface Impoundments (SI) Source Model Inputs

Table L-3 Tank Source Model Inputs

Table L-1. Landfill Source Model Inputs

Variable ID	Parameter	Units	Type	Value	Comments	Reference
Bulk waste						
DRZ_W	Depth (root zone in LF waste zone)	cm	Constant	50	Minimum value used to maintain some evaporation. Parameter does not actually represent roots present in the landfill.	Best professional judgment
porW	Porosity (total, waste)	Volume fraction	Constant	0.41	Used the average value from four soil textures as a surrogate; assumes soil value as good representation of industrial landfill waste	Carsel and Parrish (1988)
BDw	Dry bulk density (waste)	g/cm3 or Mg/m3	Derived	1.6	BDw = 2.65 (1-porosity)	EPA CMTP
asdm	Mode of aggregate size distribution (LF waste zone surface)	mm	Empirical	Randomly selected from: 7, 3, 1.5, 0.75, 0.375, 0.135		Derived from AP-42 (U.S. EPA, 1985) and TSDF Survey (U.S. EPA, 1989)
KsatW	Saturated hydraulic conductivity (waste)	cm/h	Empirical correlated	Four soil textures used to characterize the waste	Assumes soil value as good representation of industrial landfill waste	Carsel and Parrish (1988)
SMbW	Soil moisture coefficient b (waste)	Unitless	Empirical correlated	Four soil textures used to characterize the waste	Assumes soil value as good representation of industrial landfill waste	Clapp and Hornberger (1978)
SMFC_W	Soil moisture field capacity (LF waste zone)	Fraction	Empirical correlated	Four soil hydrogeologic groups used to characterize the waste	Assumes soil value as good representation of industrial landfill waste; values used in mode were fractions	Carsel et al. (1988)
SMWP_W	Soil moisture wilting point (LF waste zone)	Fraction	Empirical correlated	Four soil hydrogeologic groups used to characterize the waste	Assumes soil value as good representation of industrial landfill waste; values used in mode were fractions	Carsel et al. (1988)
focW	Fraction organic carbon (waste)	Mass fraction	Triangular	Minimum = 0.001; maximum = 0.9; typical = 0.15		Best professional judgment
SrcPh	Average waste/source pH	Unitless	Uniform	Minimum = 4; maximum = 10	Parameter does not influence model results; used to calculate Koc of pentachlorophenol	Best professional judgment
Sw	Silt content (waste)	Mass %	Uniform	Minimum = 2.2; maximum = 21	Municipal landfill roads	AP-42 (U.S. EPA, 1985) Table 13.2.2-1.

Table L-1. Landfill Source Model Inputs

Variable ID	Parameter	Units	Type	Value	Comments	Reference
Chemical						
ChemAerBioRate	Aerobic biodegradation rate	1/d	Constant	Chemical-specific	Organics only; used degradation rate for soil	See Appendix D
ChemADiff	Air diffusion coefficient	cm2/s	Constant	Chemical specific		See Appendix D
ChemAnaBioRat	Anaerobic biodegradation rate	1/d	Constant	Chemical-specific	Organics only; used degradation rate for sediment	See Appendix D
ChemCASID	CAS number	Unitless	Constant	Chemical-specific		See Appendix D
ChemHydRate	Catalyzed hydrolysis	1/d	Constant	Chemical-specific	Organics only	See Appendix D
ChemName	Chemical name	Unitless	Constant	Chemical-specific		See Appendix D
ChemType	Chemical type (O,M,Hg,S,D)	Unitless	Constant	Chemical-specific		
CTPwaste	Constituent concentration in waste (dry)	ug/g	Constant	1	Assumed value of 1 since model is linear	
ChemHLC	Henry's law constant	(atm-m3)/mol	Constant	Chemical-specific	Organics and elemental mercury only	See Appendix D
ChemKoc	Soil water partitioning coefficient	mL/g	Constant	Chemical-specific	Organics only	See Appendix D
ChemSol	Solubility for each media	mg/L	Constant	Chemical-specific	Organics and mercury only; other metals set to a default of 1,000,000 ppm.	See Appendix D
ChemTemp	Temperature assumed for these properties	degreesC	Constant	25 degreesC	Temperature at which chemical properties are derived; model has a temperature correction algorithm	
ChemWDiff	Water diffusion coefficient	cm2/s	Constant	Chemical-specific		See Appendix D
ChemFracNeutral	Fraction of chemical concentration in the neutral species at a given pH and T	Fraction	Constant or derived	1 for all chemicals except pentachlorophenol	Only pentachlorophenol was ionizing in the assumed pH range of waste	See Appendix D
ChemKd	Partition coefficient medium	L/Kg	Derived, empirical, log uniform, or pH-based isotherm	Chemical-specific	Function of KOC and POM for organics; chosen from distributions developed using literature values for metals and pH-based value for pentachlorophenol	See Appendix D
Meteorological						
SiteLatitude	Site latitude	Degrees	Constant	Site-specific		
MetSta	MetStation ID	Unitless	Empirical	Location chosen for 10,000 iterations using a weighted distribution of 49 met stations	Locations were weighted based on the volume of paint manufactured in each state divided among the met stations chosen in a given sta	

Table L-1. Landfill Source Model Inputs

Variable ID	Parameter	Units	Type	Value	Comments	Reference
Soil						
focC	Fraction organic carbon (cover soil)		Constant	Site-specific		See Appendix I
KsatC	Saturated hydraulic conductivity (LF cover soil)	cm/h	Constant	Site-specific	Mean value for a given soil texture (i.e., soil index); assumed to be the same as for vadose zone (i.e., VadSATK)	See Appendix I
WCS_C	Saturated water content (coversoil, total porosity)	L/L	Constant	Site-specific	Mean value for a given soil texture (i.e., soil index); assumed to be the same as for vadose zone (i.e., VadWCS)	See Appendix I
SOILID	Soil Index (soil)	Integer	Constant	Site-specific	Average type within a 20-mi radius; assumed to be the same as vadose zone soil texture	See Appendix I
SMbC	Soil moisture coefficient b (LF cover soil)	Unitless	Constant	Site-specific	Assumed to be the same value as for vadose zone.	See Appendix I
Vadose						
VadTemp	Average vadose zone temperature	degreesC	Constant	Site-specific	From groundwater temperature map; average for 20-mi radius around location. Assumes groundwater temperature is an indicator of vadose zone temperature	See Appendix I
focS_lf	Fraction organic carbon (subsoil)	Mass fraction	Constant	Site-specific		See Appendix I
VadSATK	Saturated hydraulic conductivity (subsoil)	cm/h	Constant	Site-specific	Mean value for a given soil texture (i.e., soil index)	See Appendix I
VadWCS	Saturated water content (subsoil)	L/L	Constant	Site-specific	Mean value for a given soil texture (i.e., soil index)	See Appendix I
SOILID	Soil index (vadose)	Integer	Constant	Site-specific	Average type within a 20-mi radius	See Appendix I
SMbS	Soil moisture coefficient b (subsoil)	Unitless	Constant	Site-specific		See Appendix I
Waste stream						
mcW	Volumetric water content (waste on trucks) - combined solids	Volume %	Uniform	Minimum = 25; maximum = 85		Derived from waste sampling data provided by U.S. EPA
mcW	Volumetric water content (waste on trucks) - dust	Volume %	Uniform	Minimum = 0; maximum = 15		Derived from waste sampling data provided by U.S. EPA

Table L-1. Landfill Source Model Inputs

Variable ID	Parameter	Units	Type	Value	Comments	Reference
WMU LF						
	Active life of landfill	yr	Constant	30		Best professional judgment
	Empty weight (trucks)	Mg	Constant	Landfill-specific	Large trucks empty weight = 30 Mg, small trucks empty weight = 15 Mg	
fwmu	Fraction of paint waste in WMU	Mass Fraction	Constant	1	Model was run assuming all waste from paint manufacturing	
SrcNumLWS	Number of local watersheds	Unitless	Constant	1		Model assumption
Nly	Number of waste layers in a cell	Unitless	Constant	Landfill-specific	If depth <=1, Nly=1; if 1>depth<=2, Nly=2; if depth>2, Nly = Integer (SrcDepth)	Best professional judgment
	Payload volume	m3	Constant	Landfill-specific	Small truck = 10; large truck = 23	Midrange value and maximum value from range in Overcash and Pal (1979)
	Size of truck	Unitless	Constant	Landfill-specific	If waste loading rate (dry)>=30,000 Mg/yr assume large trucks; if waste loading rate (dry)<30,000 Mg/yr, assume small trucks	
SrcType	Source type	Unitless	Constant	LF		
Nop	Spreading/compacting operations per day	1/d	Constant	Landfill-specific	nop = number of vehicles/day, with a maximum of 2	Best professional judgment
zS	Thickness of liner (or subsoil zone)	m	Constant	0	Model scenario assumes an unlined landfill	
zW	Waste zone thickness	m	Constant	Landfill-specific	Equal to the depth of the landfill	OSW Industrial D Screening Survey
	Wet bulk density (waste)	g/cm3 or Mg/m3	Constant	1.8	Calculated assuming 50% of pore space is filled with water and a particle density of 2.65 g/cm3. BD = 2.65(1-porosity)	
nw	Wheels per vehicle (mean)	Unitless	Constant	Landfill-specific	6 for a small truck, 10 for a large truck	Best professional judgment based on information from Overcash and Pal (1979) and MRI (1990).
	Average landfill capacity	Mg	Derived	Landfill-specific	Total capacity for all landfills at the facility (Mg) / Number of landfills at the facility	Calculated from Industrial D Screening Survey
SrcArea	Average surface area	m2	Derived	Landfill-specific	Total surface area for all landfills at the facility (m2) / Number of landfills at the facility	Calculated from OSW Industrial D Screening Survey
mt	Distance vehicle travels on active LF cell surface	m	Derived	Landfill-specific	mt = average area of landfill (m2)^1/2	Best professional judgment based on Industrial D Screening Survey landfill surface area data.
fd	Frequency of surface disturbance per month (active LF cell)	1/mo	Derived	Landfill-specific	Spreading and compacting operations per day * 30 d/mon	Best professional judgment

Table L-1. Landfill Source Model Inputs

Variable ID	Parameter	Units	Type	Value	Comments	Reference
	Payload weight (carrying capacity of truck)	Mg	Derived	Landfill-specific	Payload weight (Mg) = Payload volume (m3) * Wet bulk density (Mg/m3)	
SrcDepth	Source depth	m	Derived	Landfill-specific	Average landfill capacity (Mg)/(Average area of landfill (m2) * Wet bulk density (Mg/m3))	Calculated from OSW Industrial D Screening Survey
vw	Vehicle weight (mean)	Mg	Derived	Landfill-specific	vw = (payload (Mg))/2 + empty weight (Mg)	Best professional judgment.
nv	Vehicles/day (mean annual)	1/d	Derived	Landfill-specific	nv = average landfill capacity (Mg) / (active life of landfill (yr) * payload (Mg) * 365.25 (d/yr))	Best professional judgment
load	Waste loading rate (dry)	Mg/y	Derived	Landfill-specific	Load = average landfill capacity (Mg) / Active life of landfill (yr)	Calculated from OSW Industrial D Screening Survey
Lc	Roughness ratio (LF waste zone surface)	Unitless	Lognormal	Minimum = 1E-04; maximum = 1E-03; mean = 3E-04; standard deviation = 0.304		Best professional judgment based on U.S. EPA (1989)
effdust	Dust suppression control efficiency	Unitless	Normal	Minimum = 0; maximum = 1; mean = 0.5; standard deviation = 0.3		Best professional judgment based on U.S. EPA (1989)
veg	Fraction vegetative cover (inactive LF cell)	Fraction	Normal	Minimum = 0.8; maximum = 1; mean = 0.9; standard deviation = 0.1	Assumes landfill cover is vegetated once unit is closed	Best professional judgment.
zruf	Roughness height (inactive LF cell)	cm	Normal	Minimum = 2; maximum = 4; mean =3; standard deviation = 0.6	Uses HWIR distribution	Best professional judgment based on U.S. EPA (1989).
vs	Vehicle speed	km/h	Normal	Minimum = 20; maximum = 40; mean = 30; standard deviation = 6.		Overcash and Pal provide a range of 20-40 km for trucks traveling on the landfill
zC	Optional soil cover thickness	m	Triangular	Minimum = 0.3; maximum = 0.9; mean = 0.6	Assumes a simple soil cover designed to support vegetative cover	Best professional judgment, based on Tchobanoglous et al. (1979) and Bagchi (1990)

Table L-2. Surface Impoundments (SI) Source Model Inputs

Code	Parameter Name	Units	Type	Value	Comments	Reference
Bulk waste						
CBOD	BOD (influent)	g/cm3	Triangular	Minimum = 0, maximum = 0.1, typica value = 0.01		Best professional judgment
rho_l	Density (liquid [water])	g/cm3	Constant	0.998		Weast, 1979, CRC Handbook of Chemical and Physical Properties, 53rd ed. (1972-1973)
focW	Fraction organic carbon (waste solids)	Mass fraction	Triangular	Minimum = 0.001, maximum = 0.99, typical value = 0.35		Best professional judgment
MWt_H2O	Molecular weight (liquid [water])	g/mol	Constant	18		
dmeanTSS	Particle diameter (mean, waste suspended solids)	cm	Triangular	Minimum = 0.0005, maximum = 0.0025, typical value = 0.001		Best professional judgment
rho_part	Solids density	g/cm3	Triangular	Minimum = 1, maximum = 4, typical value = 2.5		Best professional judgment
SrcTemp	Temperature of waste	degrees Celsius	Constant	Site-specific	Set to the average ambient air temperature for each location considered.	See Appendix I
TSS_in	Total suspended solids (influen	g/cm3	Triangular	Minimum = 0.0001, maximum = 0.01, typical value = 0.001		Best professional judgment
SrcPh	Waste pH	pH units	Uniform	Minimum = 4, maximum = 10	pH was used to calculate the fraction of neutral species for pentachlorophenol, which was the only ionizing organic in the analysis	Best professional judgment
Model parameter						
NyrMax	Maximum model simulation time	Year	Constant	200	Set value due to computer memory constraints and run-time considerations	
WMU SI						
area_ag	Area agitated per aerator	m2/hp	Triangular	Minimum = 0.11, maximum = 20.2, likeliest = 5.22		U.S. EPA (1990)
SrcArea	Area of the surface impoundment	m2	Calculated	SrcArea = total area of all surface impoundments at a facility / number of SIs at a facility		Industrial D Screening Survey (Schroeder et al., 1987); average values
kba1	Biologically active solids/total solids (ratio)	Unitless	Uniform	Minimum = 0.7, maximum = 0.9		Tchobanoglous et al. (1979)
bio_yield	Biomass yield	g/g	Uniform	Minimum = 0.4, maximum = 0.8		Tchobanoglous et al. (1979)

Table L-2. Surface Impoundments (SI) Source Model Inputs

Code	Parameter Name	Units	Type	Value	Comments	Reference
d_wmu, SrcDepth	Depth of source	m	Calculated	Capacity / (SrcArea x bulk density). Bulk density is assumed to be 1 g/cm3		Derived from Industrial D Screening Survey; assumed BD = 1g/cm3; depth constraint 0.3 to 46 m
k_dec	Digestion (sediments)	1/s	Uniform	Minimum = 4.6E-07, maximum = 8.7E-07		Tchobanoglous et al. (1979)
EconLife	Economic life of surface impoundment	yr	Constant	50		Best professional judgment
fwmu	Fraction of paint waste in WMU	Mass Fraction	Constant	1	Modeling runs assumed all waste was from paint manufacturing.	
d_setpt	Fraction of SI occupied by sediments	Fraction	Calculated	If d_wmu<1.5, d_setpt=0.2. If 1.5>=d_wmu>5, d_setpt=(d_wmu-1.2)/d_wmu. If d_wmu>=5, d_setpt=0.76.		Best professional judgment; Tchobanoglous et al. (1979)
F_aer	Fraction surface area turbulent	Fraction	Normal	Assigned depending on aeration. HI aeration, normal distribution: minimum = 0, maximum = 1, mean = 0 .75, standard deviation = 0.1; LO aeration, normal distribution, minimum = 0.2, maximum = 0.8, mean = 0.5, standard deviation = 0.2; NO aeration, normal distribution : mean = 0.08 and a standard deviation = 0.03. Fraction is multiplied by the surface area to get turbulent area.	For no aeration, values were truncated not to exceed 10 m2 since the fraction surface area turbulent was included only to account for splash loading.	Derived from TSDR survey (U.S. EPA, 1987)
d_imp	Impeller diameter	cm	Constant	61		U.S. EPA (1990)
w_imp	Impeller speed	rad/s	Constant	126		U.S. EPA (1990)
n_imp	Impellers/aerators (number)	Unitless	Calculated	If powr<=25hp, n_imp=1; if 25 hp<powr<80 hp, randomly pick 1 or 2 for n_imp; if powr>=80, n_imp = Integer(powr/(random number between 60 and 100).		Adams and Eckenfelder (1974), WPCF, 1988
Powr	Impellers/aerators (total power)	hp	Calculated	Powr (hp) = (f_aer * SrcArea (m2))/Area agitated per aerator (m2/hp)	If powr > 5,000 hp, hp set = 5,000 and recalculate f_aer based on the new hp. If powr < 0.25, then set powr = 0.25.	
RT_max	Maximum retention time	Years	Constant	50; If RT > 50, then set RT = 50 and recalculate Qwmu =(ScrArea *ScrDepth)/50, such that RT = 50	Retention time was capped at 50 years to avoid unrealistically high values.	Best professional judgment
NumEcon	Number of economic lifetimes	Unitless	Constant	1		Best professional judgment

Table L-2. Surface Impoundments (SI) Source Model Inputs

Code	Parameter Name	Units	Type	Value	Comments	Reference
O2eff	Oxygen transfer correction factor	Unitless	Constant	0.83		Tchobanoglous et al. (1979)
J	Oxygen transfer factor	lb O2/h-hp	Constant	3		Tchobanoglous et al. (1979)
TermFrac	Peak output fraction for simulation termination	Fraction	Constant	0.01	Used to trigger model to stop running when concentration becomes a small fraction of the original mass in the landfill.	
RT	Retention time	Years	Calculated	d_wmu*Scr Area / Q wmu	Retention time was calculated to identify SIs with extremely high retention times.	
hydc_sed	Saturated hydraulic conductivity (sediment layer)	m/s	Uniform	Minimum = 1E-9, maximum = 1E-6		Best professional judgment
Q_wmu	Volumetric influent flow rate	m3/s	Calculated	Q_wmu = annual waste quantity/(365.25 (d/y) x (86,400 (s/d) x bulk density). BD is assumed to be 1g/cm3.		Derived from Industrial D Screening Survey
SrcType	WMU type	Unitless	Constant	SI		-

Table L-3. Tanks Source Model Inputs

Code	Parameter Name	Units	Type	Value	Comments	Reference
Bulk waste						
CBOD	BOD (influent)	g/cm3	Triangular	Minimum = 0, maximum = 0.1, typical value = 0.01		Best professional judgment
rho_l	Density (liquid [water])	g/cm3	Constant	0.998		Weast, 1979, CRC Handbook of Chemical and Physical Properties, 53rd ed. (1972-1973)
focW	Fraction organic carbon (waste solids)	Mass fraction	Triangular	Minimum = 0.001, maximum = 0.99, typical value = 0.35		Best professional judgment
MWt_H2O	Molecular weight (liquid [water])	g/mol	Constant	18		
dmeanTSS	Particle diameter (mean, waste suspended solids)	cm	Triangular	Minimum = 0.0025, maximum = 0.000! typical value = 0.001		Best professional judgment
rho_part	Solids density	g/cm3	Triangular	Minimum = 1, maximum = 4, typical value = 2.5		Best professional judgment
SrcTemp	Temperature of waste	Degrees Celsius	Constant	Site-specific	Set to the average ambient air temperature for each location considered	See Appendix I
TSS_in	Total suspended solids (influen	g/cm3	Triangular	Minimum = 0.00001, maximum = 0.01, typical value = 0.001		Best professional judgment
SrcPh	Waste pH	Unitless	Uniform	Minimum = 4, maximum = 10	pH was used to calculate the fraction of neutral species for pentachlorophenol which was the only ionizing organic in the analysis.	Best professional judgment
WMU Tank						
	Aeration level			HI, LO, or NO		
SrcArea	Area of the source	m2	Calculated	Calculated based on tank volume and projected tank depth (d_wmu)		Derived from TSDR survey (U.S. EPA, 1987)
kba1	Biologically active solids/total solids (ratio)	Unitless	Uniform	Minimum = 0.7, maximum = 0.9		Tchobanoglous (1979)
bio_yield	Biomass yield	g/g	Uniform	Minimum = 0.4, maximum = 0.8		Tchobanoglous et al. (1979)
d_wmu	Depth of source	m	Calculated	Depth = 10^[0.1358xlog(tank capacity, m3)+0.2236]	Calculated using tank capacity and aeration designations. The calulation uses a random variation on calculated depths.	Derived from TSDR survey (U.S. EPA, 1987)

Table L-3. Tanks Source Model Inputs

Code	Parameter Name	Units	Type	Value	Comments	Reference
k_dec	Digestion (sediments)	1/s	Uniform	Minimum = 4.6E-07, maximum = 8.7E-07		Tchobanoglous et al. (1979)
EconLife	Economic life of tank	yr	Constant	20		Best professional judgment
fwmu	Fraction of paint waste in WMU	Mass fraction	Constant	1	Modeling runs assumed all waste was from paint manufacturing.	
d_setpt	Fraction of tank occupied by sediments	Fraction	Constant	0.3		Best professional judgment
F_aer	Fraction surface area turbulent	Fraction	Normal	Assigned depending on aeration. HI aeration, normal distirbution: minimum = 0, maximum = 1, mean = 0 .75, standard deviation = 0.1; LO aeration, normal distribution, minimum = 0.2, maximum = 0.8, mean = 0.5, standard deviation = 0.2; NO aeration, normal distribution : mean = 0.08 and a standard deviation = 0.03.	For no aeration, values were truncated not to exceed 10 m2 since the fraction surface area turbulent was included only to account for splash loading.	Derived from TSDR survey (U.S. EPA, 1987)
d_imp	Impeller diameter	cm	Constant	61		U.S. EPA (1990)
w_imp	Impeller speed	rad/s	Constant	126		U.S. EPA (1990)
n_imp	Impellers/aerators (number)	Unitless		If powr <=25, n_imp=1; if 25hp<powr<80hp, randomly pick 1 or 2; if powr>=80 hp, n_imp = integer (powr/[random number between 60 and 100])		Adams and Eckenfelder (1974), WPCF, 1988
Powr	Impellers/aerators (total power)	hp		Assigned depending on aeration. HI aeration, normal distribution: 90% between 80 and 150 hp per million gallons of tank volume; LO and NO aeration, normal distirbution: 90% between 15 and 45 hp per million gallon of tank volume; NO aeration only was multiplied by the fraction aerated to estimate total power; minimum value was 0.25.		Tchobanoglous et al. (1979); Adams and Eckenfelder (1974), WPCF, 1988; minimum total power based on the minimum size of commercially available mixers for containers holding 55 gal or more.

Table L-3. Tanks Source Model Inputs

Code	Parameter Name	Units	Type	Value	Comments	Reference
RT_max	Maximum retention time	Years	Calculated	1; If RT > 1, then set RT = 1 and recalculate Qwmu =(ScrArea *ScrDepth)/1, such that RT = 1	When the retention time in a tank exceeded 1 year, Q_wmu was recalculated based on a retention time of a year. This avoided extremely long retention times in the source modeling, which would cause all the liquid in the tank to evaporate.	
NumEcon	Number of economic lifetimes	Unitless	Constant	2.5		Best professional judgment
O2eff	Oxygen transfer correction factor	Unitless	Constant	0.83		Tchobanoglous et al. (1979)
J	Oxygen transfer factor	lb O2/h-hp	Constant	3		Tchobanoglous et al. (1979)
RT	Retention time	Years	Calculated	d_wmu*Scr Area / Q wmu	Retention time was calculated to identify tanks with extremely high retention times.	
Q_wmu	Volumetric influent flow rate	m3/s		Derived from TSDR Survey		TSDR survey (U.S. EPA, 1987)
SrcType	WMU type	Unitless		Tank		

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Appendix M

Direct and Indirect Exposure Equations

Table M-1.1. Total Air Concentration (Vapor + Particulate)

$$C_{Air} = Q \times (F_v \times Cyv + (1 - F_v) \times Cyp) \times 0.001$$

Parameter	Definition	Input Value
C_{Air}	Total air concentration (mg/m^3)	
Q	Emission rate (g/s)	Default = 1
F_v	Fraction of air concentration in vapor phase (unitless)	For tanks and surface impoundments, 1 For landfills, calculated based on source model results
Cyv	Normalized vapor air concentration (μg-s/g-m^3)	Modeled ISC3
Cyp	Normalized particulate air concentration (μg-s/g-m^3)	Modeled ISC3
0.001	Units conversion factor (mg/μg)	

Description
This equation is used to calculate the constituent concentration in the air, which is used to determine the inhalation of contaminant.

U.S. EPA, 1998b.

Table M-1.2. Vapor Air Concentration

$$C_{vapor} = Q \times F_v \times Cyv \times 0.001$$

Parameter	Definition	Input Value
C_{vapor}	Vapor air concentration (mg/m^3)	
Q	Emission rate (g/s)	Default = 1
F_v	Fraction of air concentration in vapor phase (unitless)	For tanks and surface impoundments, 1 For landfills, calculated based on source model results
Cyv	Normalized vapor air concentration ($\mu g\text{-}s/g\text{-}m^3$)	Modeled ISC3
0.001	Units conversion factor ($mg/\mu g$)	

Description

This equation is used to calculate the constituent concentration in the vapor phase.

U.S. EPA, 1998b.

Table M-1.3. Deposition Term for Plants (Vapor)

$$D_v = 1000 \times Q \times F_v \times (Dydv + (F_w \times Dywv))$$

$$Dydv = 0.31536 \times Cyv \times Vdv$$

Parameter	Definition	Input Value
D_v	Deposition term for plants - vapor (mg/m^2-yr)	
Q	Emission rate (g/s)	Default = 1
F_v	Fraction of air concentration in vapor phase (unitless)	For tanks and surface impoundments, 1 For landfills, calculated based on source model results
F_w	Fraction of wet deposition adhering to plant surface (unitless)	Constant (see Appendix D)
Dydv	Dry deposition of vapor (s/m^2-yr)	Modeled ISC3
Dywv	Wet deposition of vapor (s/m^2-yr)	Modeled ISC3
Cyv	Normalized vapor air concentration (μg-s/g-m^3)	Modeled ISC3
Vdv	Dry deposition velocity (cm/s)	Chemical-specific (see Appendix D)
1000	Units conversion factor (mg/g)	
0.31536	Units conversion factor (m-g-s/cm-μg-yr)	
Description		
This equation is used to calculate the deposition term for plants, which is used in the plant uptake equations.		

U.S. EPA, 1998b.

Table M-1.4. Deposition Term for Plants (Particulate)

$$D_p = 1000 \times Q \times (1 - F_v) \times (Dydp + (F_w \times Dywp))$$

Parameter	Definition	Input Value
D_p	Deposition term for plants - particulate (mg/m^2-yr)	
Q	Emission rate (g/s)	Default = 1
F_v	Fraction of air concentration in vapor phase (unitless)	For tanks and surface impoundments, 1 For landfills, calculated based on source model results
F_w	Fraction of wet deposition adhering to plant surface (unitless)	Constant (see Appendix D)
Dydp	Dry deposition of particles (s/m^2-yr)	Modeled ISC3
Dywp	Wet deposition of particles (s/m^2-yr)	Modeled ISC3
1000	Units conversion factor (mg/g)	

Description
This equation is used to calculate the deposition term for plants, which is used in the plant uptake equations.

U.S. EPA, 1997b.

Table M-2.1. Soil Concentration

Noncarcinogens

$$C_{soil_{T_d}} = \frac{(Ds + L_{soil}) \times (1 - \exp(-K_s \times T_d)}{K_s}$$

Carcinogens

$$T_2 > T_d$$

$$C_{soil} = \left\{ \left[\frac{[(Ds + L_{soil}) \times T_d] - C_{soil_{T_d}}}{K_s} \right] + \left[\frac{Csoil_{T_d}}{K_s} \times \{1 - \exp[-K_s \times (T_2 - T_d)]\} \right] \right\} / (T_2 - T_1)$$

$$T_2 \le T_d$$

$$C_{soil} = \frac{(Ds + L_{soil})}{K_s \times (T_d - T_1)} \times \left[\left(T_d + \frac{\exp(-K_s \times T_d)}{K_s} \right) - \left(T_1 + \frac{\exp(-K_s \times T_1)}{K_s} \right) \right]$$

Parameter	Definition	Input Value
$Csoil_{Td}$	Average soil concentration for last year of exposure (mg/kg)	
C_{soil}	Average soil concentration over exposure duration (mg/kg)	
Ds	Deposition term for soil (mg/kg-yr)	Calculated (see Table M-2.3)
K_s	Soil loss constant (1/yr)	Calculated (see Table M-2.4)
L_{soil}	Total soil loading from buffer (mg/kg-yr)	Calculated (see Table M-2.2)
ED	Exposure duration (yr)	Exposure parameter (see Appendix G)
T_1	Time at which exposure begins (yr)	Fate parameter (see Appendix F)
T_2	Time at which exposure ends (yr)	Fate parameter (see Appendix F)
T_d	Time period of WMU operation (yr)	Fate parameter (see Appendix F)

Description
This equation is used to calculate the soil concentration for the buffer, agricultural field, and the point estimate for human ingestion. The parameter L_{soil} is only used in calculation for the agricultural field, everywhere else L_{soil} equals zero.

U.S. EPA, 1998a.

Table M-2.2. Loading Term for Soil

$$L_{soil} = \frac{\left(\dfrac{L_{ri} + L_r + L_e}{Z \times BD}\right) \times 100}{Area}$$

Parameter	Definition	Input Value
L_{soil}	Total soil loading from buffer (mg/kg-yr)	
L_{ri}	Impervious runoff load to soil (g/yr)	Impervious surfaces not evaluated
L_r	Pervious runoff load to soil (g/yr)	Calculated (see Table M-3.7)
L_e	Erosion load to soil (g/yr)	Calculated (see Table M-3.8)
Z	Mixing depth of soil - untilled (cm)	Fate parameter (see Appendix I)
BD	Bulk density of soil (g/cm^3)	Site-specific (see Appendix F)
Area	Area receiving pollutant deposition (m^2)	Fate parameter (see Appendix I)
100	Units conversion factor ($mg\text{-}m^2/kg\text{-}cm^2$)	

Description

This equation is used to calculate the loading from the buffer to the agricultural field.

Adapted from IEM, 1998b.

Table M-2.3. Deposition Term for Soil

$$Ds = \frac{100 \times Q}{Z \times BD} \times \left(F_v \times (0.31536 \times Vdv \times Cyv + Dywv) + ((Dydp + Dywp) \times (1 - F_v))\right)$$

Parameter	Definition	Input Value
Ds	Deposition term for soil (mg/kg-yr)	
Q	Emission rate (g/s)	Default = 1
Z	Soil mixing depth (cm)	Fate parameter (see Appendix F)
BD	Bulk density of soil (g/cm^3)	Site-specific (see Appendix F)
F_v	Fraction of air concentration in vapor phase (dimensionless)	For tanks and surface impoundments, 1 For landfills, calculated based on source model results
Vdv	Dry deposition velocity (cm/s)	Chemical-specific (See Appendix D)
Cyv	Normalized vapor phase air concentration ($\mu g\text{-}s/g\text{-}m^3$)	Modeled ISC3
Dywv	Normalized yearly wet deposition from vapor phase ($s/m^2\text{-}yr$)	Modeled ISC3
Dydp	Normalized yearly dry deposition from particle phase ($s/m^2\text{-}yr$)	Modeled ISC3
Dywp	Normalized yearly wet deposition from particle phase ($s/m^2\text{-}yr$)	Modeled ISC3
0.31536	Units conversion factor (m-g-s/cm-µg-yr)	
100	Units conversion factor ($mg\text{-}m^2/kg\text{-}cm^2$)	

Description
This equation calculates average air deposition occurring over the exposure duration as a result of wet and dry deposition of particles onto soil, deposition of wet vapors onto soil, and diffusion of dry vapors into soil. Contaminants are assumed to be incorporated only to a finite depth (the mixing depth, Z).

U.S. EPA, 1998b.

Table M-2.4. Soil Loss Constant

$$K_s = ksl + kse + ksr + ksg + ksv + ksh$$

Parameter	Definition	Input Value
K_s	Soil loss constant (1/yr)	
ksl	Loss constant due to leaching (1/yr)	Calculated (see Table M-2.5)
kse	Loss constant due to erosion (1/yr)	Calculated (see Table M-2.7)
ksr	Loss constant due to runoff (1/yr)	Calculated (see Table M-2.10)
ksg	Soil degradation rate (1/yr)	Chemical Specific (see Appendix D)
ksv	Loss constant due to volatilization (1/yr)	Calculated (see Table M-2.11)
ksh	Hydrolysis rate (1/yr)	Chemical-specific (see Appendix D)

Description
This equation calculates the constituent loss constant, which accounts for the loss of constituent from soil by multiple mechanisms.

U.S. EPA, 1998b.

Table M-2.5. Loss Constant Due to Leaching

$$ksl = \frac{Q_{recharge}}{\theta \times Z \times [1.0 + (BD \times Kd / \theta)]}$$

Parameter	Definition	Input Value
ksl	Loss constant due to leaching (1/yr)	
$Q_{recharge}$	Average annual recharge rate (cm/yr)	Site data (see Appendix I)
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table M-2.6)
Z	Mixing depth of soil (cm)	Fate parameter (see Appendix F)
BD	Soil bulk density (g/cm^3)	Site-specific (see Appendix I)
Kd	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix D)

Description
This equation calculates the constituent loss constant due to leaching from soil.

U.S. EPA, 1998b.

Table M-2.6. Soil Volumetric Water Content

$$\theta = n \times \left(\frac{Q_{recharge}}{K_s} \right)^{\frac{1}{(2b+3)}}$$

Parameter	Definition	Input Value
θ	Soil volumetric water content (mL/cm^3)	
n	Saturated volumetric water content (mL/cm^3)	Site-specific (see Appendix I)
$Q_{recharge}$	Average annual recharge rate (cm/yr)	Site-specific (see Appendix I)
K_s	Saturated hydraulic conductivity (cm/yr)	Site-specific (see Appendix I)
b	Soil-specific exponent representing water retention (unitless)	Site-specific (see Appendix I)

Description
This equation calculates the volumetric water content of the soil.

U.S. EPA, 1998b.

Table M-2.7. Loss Constant Due to Erosion

$$kse = \left(\frac{0.1 \times ER \times X_e \times SD}{BD \times Z} \right) \times \left(\frac{Kd \times BD}{\theta + (Kd \times BD)} \right)$$

Parameter	Definition	Input Value
kse	Loss constant due to erosion (1/yr)	
ER	Soil enrichment ratio (unitless)	Fate parameter (see Appendix F)
X_e	Universal soil loss equation (kg/m^2-yr)	Calculated (see Table M-2.8)
SD	Sediment delivery ratio (unitless)	Calculated (see Table M-2.9)
BD	Bulk density of soil (g/cm^3)	Site-specific (see Appendix I)
Z	Mixing depth of soil (cm)	Fate parameter (see Appendix F)
Kd	Soil-water partition coefficient (mL/g)	Chemical-specific (see Appendix D)
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table M-2.6)
0.1	Units conversion factor (g/kg) (m^2/cm^2)	

Description

This equation calculates the constituent loss constant due to runoff from soil.

U.S. EPA, 1998b.

Table M-2.8. Universal Soil Loss Equation

$$X_e = R \times k \times LS \times c \times P \times \frac{907.18}{4047}$$

Parameter	Definition	Input Value
X_e	Universal soil loss equation (kg/m^2 -yr)	
R	USLE rainfall erosivity factor (1/yr)	Site-specific (see Appendix I)
k	USLE soil erodibility factor (short tons/acre)	Site-specific (see Appendix I)
LS	USLE length-slope factor (unitless)	Site-specific (see Appendix I)
c	USLE cover management factor (unitless)	Fate parameter (see Appendix F)
P	USLE erosion control practice factor (unitless)	Fate parameter (see Appendix F)
907.18	Units conversion factor (kg/ton)	
4047	Units conversion factor (m^2/acre)	

Description
This equation is used to calculate the soil loss rate from the residential plot using the Universal Soil Loss Equation (USLE).

U.S. EPA, 1998b.

Table M-2.9. Sediment Delivery Ratio

$$SD = A \times (Area)^{-B}$$

Parameter	Definition	Input Value
SD	Sediment delivery ratio (unitless)	
A	Empirical intercept coefficient chosen based on the size of the area (unitless)	0.6
Area	Area receiving pollutant deposition (m^2)	Site-specific (see Appendix I)
B	Empirical slope coefficient related to the power of the drainage area (unitless)	Site-specific (see Appendix I)
Description		
This equation is used to calculate the sediment delivery ratio.		

U.S. EPA, 1998b.

Table M-2.10. Loss Constant Due to Runoff

$$ksr = \frac{Rf}{\theta \times Z} \times \left(\frac{1}{1 + (Kd_s \times BD / \theta)} \right)$$

Parameter	Definition	Input Value
ksr	Loss constant due to runoff (1/yr)	
Rf	Average annual runoff (cm/yr)	Site-specific (see Appendix I)
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table M-2.6)
Z	Mixing depth of soil (cm)	Fate parameter (see Appendix F)
Kd	Soil-water partition coefficient (mL/g)	Chemical-specific (see Appendix D)
BD	Bulk density of soil (g/cm^3)	Site-specific (see Appendix I)

Description
This equation calculates the constituent loss constant due to runoff from soil.

U.S. EPA, 1998b.

Table M-2.11. Loss Constant Due to Volatilization

$$ksv = \left(\frac{3.1536E+7 \times 1000 \times HLC}{Z \times Kd \times R \times T \times BD} \right) \times \frac{Da\ (1 - (BD/\rho_s) - \theta)}{Z}$$

Parameter	Definition	Central Tendency	High End
ksv	Loss constant due to volatilization (1/yr)		
HLC	Henry's law constant (atm-m^3/mol)	Chemical-specific (see Appendix D)	
Z	Soil mixing depth (cm)	Fate parameter (see Appendix F)	
Kd	Soil-water partition coefficient (mL/g)	Chemical-specific (see Appendix D)	
R	Universal gas constant (atm-m^3/mol-K)	8.205×10^{-5}	
T	Ambient temperature (K)	Site-specific (see Appendix I)	
BD	Soil bulk density (g/cm^3)	Site-specific (see Appendix I)	
D_a	Diffusivity of constituent in air (cm^2/s)	Chemical-specific (see Appendix D)	
ρ_s	Solids particle density (g/cm^3)	2.65	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table M-2.6)	
3.1536E+7x10^7	Units conversion factor (s/yr)		
1000	Units conversion factor (L/m^3)		

Description
This equation calculates the constituent loss constant due to volatilization from soil.

U.S. EPA, 1998b.

Table M-3.1. Total Waterbody Concentration

$$C_{wt} = f_{water} \times C_{wtot} \times \frac{dz}{dw}$$

Parameter	Definition	Input Value
C_{wt}	Total waterbody concentration (g/m^3 or mg/L)	
C_{wtot}	Surface water concentration from loading (g/m^3 or mg/L)	Calculated (see Table M-3.3)
f_{water}	Fraction of contaminant in water column (unitless)	Calculated (see Table M-3.10)
dz	Depth of waterbody (m)	Fate parameter (see Appendix F)
dw	Depth of the water column (m)	Fate parameter (see Appendix F)

Description
This equation calculates the total water column concentration of a constituent; including both dissolved constituent and constituent sorbed to suspended solids.

U.S. EPA, 1998b.

Table M-3.2. Dissolved Waterbody Concentration

$$C_{dw} = C_{wtot} \times f_{water} \times fd \times \left(\frac{dz}{dw} \right)$$

Parameter	Definition	Input Value
C_{dw}	Dissolved waterbody concentration (mg/L)	
C_{wtot}	Surface water concentration from loading (mg/L)	Calculated (see Table M-3.3)
f_{water}	Fraction of contaminant in water column (unitless)	Calculated (see Table M-3.10)
fd	Dissolved fraction (unitless)	Calculated (see Table M-3.12)
dz	Depth of waterbody (m)	Fate parameter (see Appendix F)
dw	Depth of the water column (m)	Fate parameter (see Appendix F)

Description
This equation calculated the contaminant concentration in dissolved water.

U.S. EPA, 1998b.

Table M-3.3. Total Water Column Concentration from Loading

$$C_{wtot} = \frac{L_T}{Vf_x \times f_{water} + k_{wt} \times V}$$

$$V = W \quad \times (dw + db)$$

Parameter	Definition	Input Value
C_{wtot}	Total water column concentration from loading (g/m^3 or mg/L)	
L_T	Total waterbody load (g/yr)	Calculated (see Table M-3.4)
Vf_x	Flow mixing volume (m^3/yr)	Fate parameter (see Appendix F)
f_{water}	Fraction of contaminant in water column (unitless)	Calculated (see Table M-3.10)
k_{wt}	Water concentration dissipation rate constant (1/yr)	Calculated (see Table M-3.9)
V	Flow independent mixing volume (m^3)	
W_{aw}	Area of the waterbody (m^2)	Fate parameter (see Appendix F)
dw	Depth of water column (m)	Fate parameter (see Appendix F)
db	Depth of upper benthic layer (m)	Fate parameter (see Appendix F)

Description

This equation calculates the waterbody concentration.

U.S. EPA, 1998b.

Table M-3.4. Total Waterbody Load

$$L_T = L_{Dep} + L_{Dif} + L_{ri} + L_r + L_e$$

Parameter	Definition	Input Value
L_T	Total waterbody load (g/yr)	
L_{Dep}	Total deposition load to waterbody (g/yr)	Calculated (see Table M-3.5)
L_{Dif}	Diffusion load to waterbody (g/yr)	Calculated (see Table M-3.6)
L_{ri}	Impervious runoff load to waterbody (g/yr)	Impervious surfaces not evaluated
L_r	Pervious runoff load to waterbody (g/yr)	Calculated (see Table M-3.7)
L_e	Erosion load to waterbody (g/yr)	Calculated (see Table M-3.8)

Description
This equation calculates the total average waterbody load from deposition, runoff, and erosion loads.

U.S. EPA, 1998b.

Table M-3.5. Total Deposition Load to Waterbody

$$L_{Dep} = Q \times \{(F_v \times Dywv) + [(1 - F_v) \times (Dydp + Dywp)]\} \times W_{aw}$$

Parameter	Definition	Input Value
L_{Dep}	Total deposition load to waterbody (g/yr)	
Q	Emission rate (g/s)	Default = 1
F_v	Fraction of air concentration in vapor phase (unitless)	For tanks and surface impoundments, 1 For landfills, calculated based on source model results
Dywv	Normalized wet deposition from vapor phase (s/m^2-yr)	Modeled ISC3
Dydp	Normalized dry deposition from particle phase (s/m^2-yr)	Modeled ISC3
Dywp	Normalized wet deposition from particle phase (s/m^2-yr)	Modeled ISC3
W_{aw}	Area of waterbody area (m^2)	Fate parameter (see Appendix F)

Description
This equation calculates the average load to the waterbody from direct wet and dry deposition of particles and wet deposition of vapors onto the surface of the waterbody.

U.S. EPA, 1998b.

Table M-3.6. Diffusion Load to Waterbody

$$L_{Dif} = \frac{K_v \times C_{vapor} \times Waw \times 0.001}{\dfrac{HLC}{R \times T_w}}$$

Parameter	Definition	Input Value
L_{Dif}	Diffusion load to waterbody (g/yr)	
K_v	Diffusive transfer rate (m/yr)	Calculated (see Table M-3.14)
C_{vapor}	Vapor air concentration (mg/m^3)	Calculated (see Table M-1.2)
Waw	Area of the waterbody (m^2)	Fate parameter (see Appendix F)
HLC	Henry's law constant (atm - m^3/mol)	Chemical-specific (see Appendix D)
R	Universal gas constant (atm-m^3/mol-k)	8.205E-5
T_w	Waterbody temperature (K)	Fate parameter (see Appendix F)
0.001	Units conversion factor (g/mg)	

Description

This equation calculates the load to the waterbody due to vapor diffusion. Note: L_{Dif} is zero when HLC is less than zero.

U.S. EPA, 1998b.

Table M-3.7. Pervious Runoff Load to Waterbody

$$L_r = R_f \times (W_{at} - W_{ai}) \times \left(\frac{C_{soil} \times BD}{\theta + (Kd_{soil} \times BD)} \right) \times 0.01$$

Parameter	Definition	Input Value
L_r	Pervious runoff load to waterbody (g/yr)	
R_f	Average annual runoff (cm/yr)	Fate parameter (see Appendix F)
W_{at}	Total watershed area (m^2)	Fate parameter (see Apendix F)
W_{ai}	Impervious area in the watershed (m^2)	Not evaluated
C_{soil}	Chemical concentration in soil (mg/kg)	Calculated (see Table M-2.1)
BD	Soil bulk density (g/cm^3)	Site-specific (see Appendix I)
Kd_{soil}	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix D)
θ	Soil volumetric water content (mL/cm^3 or cm^3/cm^3)	Calculated (see Table M-2.6)
0.01	Units conversion factor ($kg\text{-}cm^2/mg\text{-}m^2$)	

Description
This equation calculates the average runoff load to the waterbody from pervious soil surfaces in the watershed.

U.S. EPA, 1998b.

Table M-3.8. Erosion Load to Waterbody

$$L_e = X_e \times (W_{at} - W_{ai}) \times SD \times ER \times \left(\frac{C_{soil} \times Kd_{soil} \times BD}{\theta + (Kd_{soil} \times BD)} \right) \times 0.001$$

Parameter	Definition	Input Value
L_e	Erosion load to waterbody (g/yr)	
X_e	Universal soil loss equation (kg/yr-m^2)	Calculated (see Table M-2.8)
W_{at}	Total watershed area (m^2)	Fate parameter (see Appendix F)
W_{ai}	Impervious area in the watershed (m^2)	Not Evaluated
SD	Sediment delivery ratio (unitless)	Calculated (see Table M-2.9)
ER	Soil enrichment ratio (unitless)	Fate parameter (see Appendix F)
C_{soil}	Chemical concentration in soil (mg/kg)	Calculated (see Table M-2.1)
Kd_{soil}	Soil-water partition coefficient (mL/g)	Chemical Specific (see Appendix D)
BD	Soil bulk density (g/cm^3)	Site-specific (see Appendix I)
θ	Soil volumetric water content (mL/cm^3 or cm^3/cm^3)	Calculated (see Table M-2.6)
0.001	Conversion factor (g/mg)	

Description
This equation calculates the load to the waterbody from soil erosion.

U.S. EPA, 1998b.

Table M-3.9. Water Concentration Dissipation Rate Constant

$$k_{wt} = (f_{water} \times k_v) + (f_{benth} \times k_b) + (f_{water} \times kgw) + (f_{benth} \times kgs) + kh$$

$$k_b = \frac{WB}{db}$$

$$k_v = \frac{(Kv)(fd)}{dz}$$

Parameter	Definition	Input Value
k_{wt}	Water concentration dissipation rate constant (1/yr)	
f_{water}	Fraction of contaminant in the water column (unitless)	Calculated (see Table M-3.10)
k_v	Water column volatilization rate constant (1/yr)	
f_{benth}	Fraction of contaminant in benthic sediment (unitless)	Calculated (see Table M-3.11)
k_b	Benthic burial rate constant (1/yr)	
kgw	Degradation rate for water column (1/yr)	Chemical-specific (see Appendix D)
kgs	Degradation rate for sediment (1/yr)	Chemical-specific (see Appendix D)
kh	Hydrolysis rate (1/yr)	Chemical-specific (see Appendix D)
db	Depth of the upper benthic layer (m)	Fate parameter (see Appendix F)
Kv	Diffusion transfer rate (m/yr)	Calculated (see Table M-3.14)
fd	Dissolved fraction (unitless)	Calculated (see Table M-3.12)
WB	Burial rate (m/yr)	Calculated (see Table M-3.13)
dz	Depth of the waterbody (m)	Fate parameter (see Appendix F)

Description

This equation calculates the overall dissipation rate of a constituent in surface water due to volatilization and benthic burial.

U.S. EPA, 1998b.

Table M-3.10. Fraction of Contaminant in Water Column

$$f_{water} = \frac{[1 + (Kd_{sw} \times TSS \ x \ 1E{-}6)] \times \left(\frac{dw}{dz}\right)}{\left\{[1 + (Kd_{sw} \times TSS \times 1E{-}6)] \times \left(\frac{dw}{dz}\right)\right\} + \left[(bsp + Kd_{bs} \times bsc) \times \left(\frac{db}{dz}\right)\right]}$$

Parameter	Definition	Input Value
f_{water}	Fraction of contaminant in the water column (unitless)	
Kd_{sw}	Soil-water partition coefficient for suspended sediment (mL/g)	Chemical-specific (see Appendix D)
TSS	Total suspended solids in water column (mg/L)	Fate parameter (see Appendix F)
1E-6	Conversion factor (L/mL)/(g/mg)	
db	Depth of the upper benthic layer (m)	Fate parameter (see Appendix F)
dz	Depth of waterbody (m)	Fate parameter (see Appendix F)
dw	Depth of the water column (m)	Fate parameter (see Appendix F)
bsp	Bed sediment porosity (cm^3/cm^3)	Fate parameter (see Appendix F)
Kd_{bs}	Soil-water partition coefficient for bed sediment (mL/g)	Chemical-specific (see Appendix D)
bsc	Bed sediment concentration (kg/L)	Fate parameter (see Appendix F)

Description
These equations calculate the fraction of total waterbody concentration occurring in the water column.

U.S. EPA, 1998b.

Table M-3.11. Fraction of Contaminant in Benthic Sediments

$$f_{benth} = \frac{(bsp + Kd_{bs} \times bsc)\left(\frac{db}{dz}\right)}{\left\{(1 + Kd_{sw} \times TSS \times 1E-6)\left(\frac{dw}{dz}\right)\right\} + \left\{(bsp + Kd_{bs} \times bsc)\left(\frac{db}{dz}\right)\right\}}$$

Parameter	Definition	Input Value
f_{benth}	Fraction of contaminant in benthic sediment (unitless)	
bsp	Bed sediment porosity (cm^3/cm^3)	Fate parameter (see Appendix F)
Kd_{bs}	Soil water partition coefficient for bed sediment (mL/g)	Chemical-specific (see Appendix D)
bsc	Bed sediment concentration (kg/L)	Fate parameter (see Appendix F)
db	Depth of the upper benthic layer (m)	Fate parameter (see Appendix F)
dz	Depth of the waterbody (m)	Fate parameter (see Appendix F)
Kd_{sw}	Soil water partition coefficient for suspended sediment (mL/g)	Chemical-specific (see Appendix D)
TSS	Total suspended solids in water column mg/L	Fate parameter (see Appendix F)
1E-6	Conversion factor (L/mL)(g/mg)	
dw	Depth of the water column (m)	Fate parameter (see AppendixF)

Description
These equations calculate the fraction of total waterbody concentration occurring in the bed sediments.

U.S. EPA, 1998b.

Table M-3.12. Dissolved Fraction

$$fd = \frac{1}{1 + Kd_{sw} \times TSS \times 1E-6}$$

Parameter	Definition	Input Value
fd	Dissolved fraction (unitless)	
Kd_{sw}	Soil water partition coefficient for suspended sediment (mL/g)	Chemical-specific (see Appendix D)
TSS	Total suspended solids (mg/L)	Fate parameter (see Appendix F)
1E-6	Conversion factor (g/mg) (L/mL)	
Description		
This equation calculates the concentration of constituent dissolved in the water column.		

U.S. EPA, 1998b.

Table M-3.13. Rate of Burial

$$WB = \frac{(X_e \times W_{at} \times SD \times 1000) - (Vf_x \times TSS)}{W_{aw} \times TSS} \times \frac{TSS \times 1E-6}{bsc}$$

Parameter	Definition	Input Value
WB	Burial rate (m/yr)	
X_e	Universal soil loss equation (kg/yr-m^2)	Calculated (see Table M-2.8)
W_{at}	Total area of watershed (m^2)	Fate parameter (see Appendix F)
SD	Sediment delivery ratio (unitless)	Calculated (see Table M-2.9)
Vf_x	Flow mixing volume (m^3/yr)	Fate parameter (see Appendix F)
TSS	Total suspended solids in water column (g/m^3 ≅ mg/L)	Fate parameter (see Appendix F)
W_{aw}	Waterbody surface area (m^2)	Fate parameter (see Appendix F)
bsc	Bed sediment concentration (kg/L)	Fate parameter (see Appendix F)
1E-6	Conversion factor (kg/mg)	
1000	Conversion factor (g/kg)	

Description
This equation is used to determine the loss of a constituent from the waterbody as it deposits onto the benthic sediment.

U.S. EPA, 1998b.

Table M-3.14. Diffusion Transfer Rate

$$Kv = \frac{1}{\left\{\left(\frac{1}{KL_{rivers}}\right) + \left(\frac{1}{Kgas \times H_{prime}}\right)\right\}} \times Tempadjust$$

Parameter	Definition	Input Value
Kv	Diffusion transfer rate (m/yr)	
H_{prime}	HLC/(R x Tw (unitless)	
HLC	Henry's law constant (atm -m^3/mol)	Chemical-specific (see Appendix D)
R	Universal gas constant (atm -m^3/mol-K)	8.205E-5
Tw	Waterbody temperature (K)	Fate parameter (see Appendix F)
Tempadjust	Temperature adjustment (K)	1.026 ^ (T_w - 298)
KL_{rivers}	Liquid phase transfer coefficient for rivers (m/yr)	Calculated (see Table M-3.15)
Kgas	Gas phase transfer coefficient (m/yr)	36,500

Description
This equation calculates the overall transfer rate of constituent from the liquid and gas phases in surface water.

U.S. EPA, 1998b.

Table M-3.15. Liquid Phase Transfer Coefficient for Rivers

$$KL_{rivers} = \sqrt{\frac{D_w \times V \times 0.0001}{dz}} \times 31{,}500{,}000$$

Parameter	Definition	Input Value
KL_{rivers}	Liquid phase transfer coefficient - rivers (m/yr)	
V	Current velocity (m/s)	Fate parameter (see Appendix F)
dz	Waterbody depth (m)	Fate parameter (see Appendix F)
D_w	Diffusion coefficient in water (cm^2/s)	Chemical-specific (see Appendix D)
0.0001	Units conversion factor (m^2/cm^2)	
31,500,000	Units conversion factor (s/yr)	

Description
This equation calculates the liquid phase transfer coefficients for flowing waterbodies.

U.S. EPA, 1998b.

Table M-4.1. Aboveground Concentration Due to Root Uptake

$$Pr = C_{soil} \times Br$$

Parameter	Definition	Input Value
Pr	Aboveground concentration due to root uptake (mg/kg DW)	
C_{soil}	Concentration in soil (mg/kg)	Calculated (see Table M-2.1)
Br	Soil-to-plant bioconcentration factor (μg/g DW plant)/μg/g soil)	Chemical-specific (see Appendix D)

Description
This equation calculates the constituent concentration in aboveground vegetation due to direct uptake of chemicals from soil. Aboveground concentration includes forage, silage, exposed vegetables, exposed fruits, and protected fruit.

U.S. EPA, 1998b.

Table M-4.2. Concentration in Belowground Vegetable Due to Root Uptake

For organics:

$$Pr_{bg} = \frac{C_{soil} \times RCF \times VG_{bg}}{Kd_{soil}}$$

For metals:

$$Pr_{bg} = C_{soil} \times Br \times DWr$$

Parameter	Definition	Input Value
Pr_{bg}	Concentration in belowground vegetable due to root uptake (mg/kg ww)	
C_{soil}	Concentration in soil (mg/kg)	Calculated (see Table M-2.1)
RCF	Ratio of concentration factor (μg/g ww plant)/(μg/mL soil water)	Chemical-specific (see Appendix D)
VG_{bg}	Empirical correction factor for plant uptake - root vegetables (unitless)	Fate parameter (see Appendix F)
Kd_{soil}	Soil water partition coefficient (mL/g or L/kg)	Chemical-specific (see Appendix D)
Br	Soil-to-plant bioconcentration factor (μg/g DW plant)/μg/g soil	Chemical-specific (see Appendix D)
DWr	Dry weight fraction for root vegetables (unitless)	Fate parameter (see Appendix F)

Description
This equation calculates the constituent concentration in root vegetables due to uptake from the soil water.

U.S. EPA, 1998b.

Table M-4.3. Aboveground Produce Concentration Due to Vapor Deposition

If log K_{ow} > or = 5:

$$Pv = \frac{C_{vapor} \times Bv \ x \ VG_{ag} \times 1000}{\rho_a}$$

If log K_{ow} < 5 :

$$Pv = \frac{(D_v \times Rp) \times (1 - \exp(-Kpvap \times Tp))}{Yp \times Kpvap}$$

Parameter	Definition	Input Value
Pv	Vegetative concentration due to vapor deposition (mg/kg DW)	
K_{ow}	Octanol water partition coefficient (unitless)	Chemical-specific (see Appendix D)
C_{vapor}	Concentration of vapor (mg/m^3)	Calculated (see Table M-1.2)
Bv	Air-to-plant biotransfer factor (μg/g DW plant)/μg/g air)	Chemical-specific (see Appendix D)
VG_{ag}	Empirical correction factor for aboveground plants (unitless)	Fate parameter (see Appendix F)
ρ_a	Density of air (g/m^3)	1,200
D_v	Deposition term for plants (vapor) (mg/m^2-yr)	Calculated (see Table M-1.3)
Rp	Interception fraction (unitless)	Fate parameter (see Appendix F)
Kpvap	Plant surface loss coefficient due to vapor (1/yr)	Chemical-specific (see Appendix D)
Tp	Length of plant exposure to deposition (yr)	Fate parameter (see Appendix F)
Yp	Crop yield (kg DW/m^2)	Fate parameter (see Appendix F)
1000	Correction factor (g/kg)	

Description
This equation calculates the constituent concentration in aboveground vegetation due to direct uptake of vapor phase chemical into the plant leaves.

U.S. EPA, 1998b.

Table M-4.4. Aboveground Produce Concentration Due to Direct Deposition

$$Pd = \frac{D_p \times R_p \times (1 - exp(-KpPar \times TP)}{Yp \times KpPar}$$

Parameter	Definition	Input Value
Pd	Vegetative concentration due to direct deposition (mg/kg DW)	
D_p	Deposition term for plants (mg/m^2-yr)	Calculated (see Table M-1.4)
Rp	Interception fraction (unitless)	Fate parameter (see Appendix F)
KpPar	Plant surface loss coefficient due to particulates (1/yr)	Chemical-specific (see Appendix D)
Tp	Length of plant exposure to deposition (yr)	Fate parameter (see Appendix F)
Yp	Crop yield (kg DW/m^2)	Fate parameter (see Appendix F)

Description
This equation calculates the constituent concentration in aboveground vegetation due to wet and dry deposition of constituents adsorbed to particles onto the plant surface.

U.S. EPA, 1998b.

Table M-4.5. Total Aboveground Vegetative Concentration

For forage, silage, and grain:

$$Pveg_{DW} = (Pd + Pv + Pr)$$

For exposed vegetables, protected fruit and exposed fruit:

$$Pveg_{WW} = \left[\frac{(100 - MAF)}{100} \times Pveg_{DW} \right]$$

Parameter	Description	Input Values
$Pveg_{DW}$	Total vegetative concentration in dry weight (mg/kg DW)	
Pd	Vegetative concentration due to direct deposition (mg/kg DW)	Calculated (see Table M-4.4)
Pv	Vegetative concentration due to vapor deposition (mg/kg DW)	Calculated (see Table M-4.3)
Pr	Aboveground concentration due to root uptake (mg/kg DW)	Calculated (see Table M-4.4.1)
$Pveg_{WW}$	Total vegetative concentration in wet weight (mg/kg WW)	
MAF	Plant tissue - specific moisture adjustment factor to convert DW concentration to WW concentration	Fate parameter (see Appendix F)

Description
This equation calculates the daily intake of contaminant from ingestion of aboveground vegetation.

U.S. EPA, 1998b.

Table M-4.6. Beef Concentration Due to Soil and Plant Ingestion

$$PlantIntake = (Fg \times Qpg \times Pg) + (Ff \times Qpf \times Pf) + (Fs \times Qps \times Ps)$$

$$A_{beef} = [PlantIntake + (Qs \times Csoil) + (Cwt \times Qw)] \times Ba_{Beef}$$

Parameter	Definition	Input Value
PlantIntake	Amount of vegetation consumed by beef cattle (mg/d)	
Fg	Fraction of grain grown on contaminated soil and eaten (unitless)	Fate parameter (see Appendix F)
Qpg	Quantity of grain eaten each day (kg DW/d)	Fate parameter (see Appendix F)
Pg	Vegetative concentration for grain (mg/kg DW)	Calculated (see Table M-4.5)
Ff	Fraction of forage grown on contaminated soil and eaten (unitless)	Fate parameter (see Appendix F)
Qpf	Quantity of forage eaten each day (kg DW/d)	Fate parameter (see Appendix F)
Pf	Vegetative concentration for forage (mg/kg DW)	Calculated (see Table M-4.5)
Fs	Fraction of silage grown on contaminated soil and eaten (unitless)	Fate parameter (see Appendix F)
Qps	Quantity of silage eaten each day (kg DW/d)	Fate parameter (see Appendix F)
Ps	Vegetative concentration in silage (mg/kg DW)	Calculated (see Table M-4.5)
A_{beef}	Beef concentration due to plant and soil ingestion (mg/kg WW)	
Qs	Consumption rate of soil (kg/d)	Fate parameter (see Appendix F)
C_{soil}	Concentration in the soil (mg/kg)	Calculated (see Table M-2.1)
Ba_{beef}	Beef biotransfer factor (d/kg WW)	Chemical-specific (see Appendix D)
Cwt	Total concentration in the water column (mg/L)	Calculated (see Table M-3.1)
Qw	Quantity of water consumed each day (L/d)	Fate parameter (see Appendix F)

Description
This equation calculates the concentration of constituent in beef from ingestion of forage and soil.

U.S. EPA, 1998b.

Table M-4.7. Milk Concentration Due to Plant and Soil Ingestion

$$PlantIntake = (Fg \times Qpg \times Pg) + (Ff \times Qpf \times Pf) + (Fs \times Qps \times Ps)$$

$$A_{milk} = [PlantIntake + (Qs \times Csoil) + (C_{wt} \times Qw)] \times Ba_{Milk}$$

Parameter	Definition	Input Value
PlantIntake	Amount of vegetation consumed by dairy cattle (mg/kg)	
Fg	Fraction of grain grown on contaminated soil and eaten (unitless)	Fate parameter (see Appendix F)
Qpg	Quantity of grain eaten each day (kg DW/d)	Fate parameter (see Appendix F)
Pg	Vegetative concentration for grain (mg/kg DW)	Calculated (see Table M-4.5)
Ff	Fraction of forage grown on contaminated soil and eaten (unitless)	Fate parameter (see Appendix F)
Qpf	Quantity of forage eaten each day (kg DW/d)	Fate parameter (see Appendix F)
Pf	Vegetative concentration for forage (mg/kg DW)	Calculated (see Table M-4.5)
Fs	Fraction of silage grown on contaminated soil and eaten (unitless)	Fate parameter (see Appendix F)
Qps	Quantity of silage eaten each day (kg DW/d)	Fate parameter (see Appendix F)
Ps	Vegetative concentration in silage (mg/kg DW)	Calculated (see Table M-4.5)
A_{milk}	Milk concentration due to plant and soil ingestion (mg/kg WW)	
Qs	Consumption rate of soil (kg/d)	Fate parameter (see Appendix F)
Csoil	Concentration in the soil (mg/kg)	Calculated (see Table M-2.1)
Ba_{milk}	Milk biotransfer factor (d/kg WW)	Chemical-specific (see Appendix D)
Cwt	Total concentration in the water column (mg/L)	Calculated (see Table M-4.5)
Qw	Quantity of water consumed each day (L/d)	Fate parameter (see Appendix F)

Description
This equation calculates the concentration of constituent in milk from ingestion of forage and soil.

U.S. EPA, 1998b.

Table M-4.8. Fish Concentration

For a metal:

$$C_{fish} = C_{wt} \times BCF$$

For organics and mercury:

$$C_{fish} = C_{dw} \times BCF$$

Parameter	Definition	Input Value
C_{fish}	Constituent concentration in fish tissue (mg/kg)	
C_{wt}	Total waterbody concentration (gm^3 or mg/L)	Calculated (see Table M-3.1)
BCF	Bioconcentration factor (L/kg) Two possible BCFs: trophic level 3 filets, and trophic level 4 filets	Chemical-specific (see Appendix D)
C_{dw}	Dissolved waterbody concentration (g/m^3 or mg/L)	Calculated (see Table M-3.2)

Description
This equation calculates the constituent concentration if fish tissue as the product of the bioconcentration factor and the concentration dissolved in water.

U.S. EPA, 1998b.

Table M-5.1. Daily Intake of Contaminant from Soil

$$I_{soil} = \frac{C_{soil} \times CR_s \times F_{soil}}{BW}$$

Parameter	Description	Input Values
I_{soil}	Daily intake of contaminant from soil ingestion (kg/d)	
C_{soil}	Concentration of contaminant in soil (mg/kg)	Calculated (see Table M-2.1)
CR_s	Soil ingestion rate (kg/d)	Exposure parameter (see Appendix G)
F_{soil}	Fraction of contaminated soil ingested (unitless)	Exposure parameter (see Appendix G)
BW	Body weight (kg)	Exposure parameter (see Appendix G)

Description
This equation calculates the daily intake of contaminant from soil consumption.

U.S. EPA, 1998b.

Table M-5.2. Daily Intake of Contaminant from Belowground Produce

$$I_{bg} = \frac{Pr_{bg} \times CR_{bg} \times F_{bg}}{1000}$$

Parameter	Description	Input Values
I_{bg}	Daily intake of contaminant from belowground produce (mg/kg-d)	
Pr_{bg}	Concentration of contaminant in belowground produce (mg/kg WW)	Calculated (see Table M-4.2)
CR_{bg}	Daily human consumption rate of belowground produce (g WW/kg-d)	Exposure parameter (see Appendix G)
F_{bg}	Fraction of belowground produce grown in contaminated soil (unitless)	Exposure parameter (see Appendix G)
1000	Units conversion factor (g/kg)	

Description
This equation calculates the daily intake of contaminant from ingestion of root vegetables.

U.S. EPA, 1998b.

Table M-5.3. Daily Intake of Contaminant from Aboveground Produce

$$I_{ag} = \frac{Pveg_{WW} \times CR_{ag} \times F_{ag}}{1000}$$

Parameter	Description	Input Values
I_{ag}	Daily intake of contaminant from exposed produce (mg/kg-d)	
$Pveg_{WW}$	Concentration of contaminant in aboveground produce (mg/kg)	Calculated (see Table M-4.5)
CR_{ag}	Daily human consumption rate of aboveground produce (g/kg-d)	Exposure parameter (see Appendix G)
F_{ag}	Fraction of aboveground produce grown in contaminated soil (unitless)	Exposure parameter (see Appendix G)
1000	Units conversion factor (g/kg)	

Description

This equation calculates the daily intake of contaminant from ingestion of exposed vegetation, exposed fruit, and protected fruit, on a wet weight (WW) basis. The consumption rate varies for children and adults.

U.S. EPA, 1998b.

Table M-5.4. Daily Intake of Contaminant from Ingestion of Animal Tissue

For beef:

$$I_{beef} = \frac{A_i \times CR_i \times F_i}{1000} \times CF_{beef}$$

$$CF_{beef} = (1 - L_1) \times (1 - L_2)$$

For milk:

$$I_{milk} = \frac{A_i \times CR_i \times F_i}{1000}$$

Parameter	Description	Input Values
I_{animal}	Daily intake of contaminant from ingestion of animal tissue (mg/kg-d)	
A_i	Concentration of contaminant in animal tissue (mg/kg WW)	Calculated (see Tables M-4.5, M-4.6 and M-4.7)
CR_i	Daily consumption rate of animal tissue (g WW/kg-d)	Exposure parameter (see Appendix G)
F_i	Fraction of animal tissue that is contaminated (unitless)	Exposure parameter (see Appendix G)
CF_{beef}	Correction factor for beef (unitless)	EFH, 1997 (Eqn. 13-3)
1000	Units conversion factor (g/kg)	
L_1	Percent weight cooking loss (27%)	
L_2	Percent weight postcooking loss (24%)	

Description
This equation calculates the daily intake of contaminant from ingestion of animal tissue where the "*i*" in the above equation refers to beef or dairy.

U.S. EPA, 1998b.

Table M-5.5. Daily Intake of Contaminant from Fish

$$I_{fish} = \frac{C_{fish} \times CR_{fish} \times F_{fish}}{BW \times 1000}$$

$$C_{fish\_w} = (C_{fish3F} \times F_{fish3}) + (C_{fish4F} \times F_{fish4})$$

Parameter	Description	Input Values
I_{fish}	Daily intake of contaminant from fish (mg/kg-d)	
C_{fish_w}	Weighted concentration of contaminant in fish (mg/kg)	
CR_{fish}	Consumption rate of fish (g/d)	Exposure parameter (see Appendix G)
F_{fish}	Fraction of fish that are contaminated (unitless)	Exposure parameter (see Appendix G)
BW	Body weight (kg)	Exposure parameter (see Appendix G)
1000	Units conversion factor (g/kg)	
C_{fish3F}	Concentration of contamination T_3 fish	Calculated (see Table M-4.8)
F_{fish3}	Fraction of T_3 fish that are consumed in a diet	Exposure parameter (see Appendix G)
C_{fish4F}	Concentration of contaminant in T_4 fish	Calculated (see Table M-4.8)
F_{fish4}	Fraction of T_4 fish that are consumed in a diet	Exposure parameter (see Appendix G)

Description

This equation calculates the daily intake of contaminant from ingestion of fish.

U.S. EPA, 1998b.

Table M-6.1. Risk Due to Oral Ingestion

$$Risk_{oral} = \frac{I \times ED \times EF \times CSF_{oral}}{AT \times 365}$$

Parameter	Description	Input Values
$Risk_{oral}$	Risk due to oral ingestion (unitless)	
I	Intake rate (mg/kg-d)	Calculated (see Tables M-5.1- M-5.5)
ED	Exposure duration (yr)	Exposure parameter (see Appendix G)
EF	Exposure frequency (d/yr)	Exposure parameter (see Appendix G)
AT	Averaging time (yr)	Exposure parameter (see Appendix G)
CSF_{oral}	Oral cancer slope factor $(mg/kg\text{-}d)^{-1}$	Health Benchmark (see Appendix Q)
365	Conversion factor (d/yr)	

Description
This equation calculates the individual cancer risk from indirect exposure to carcinogenic chemicals.

U.S. EPA, 1998b.

Table M-6.2. Risk Due to Inhalation of Air

$$Risk_{Air} = \frac{C_{Air} \times B_{ri} \times E_{di} \times E_{fi} \times CSF_{Inhal}}{AT \times 365 \times BW}$$

Parameter	Description	Input Values
$Risk_{Air}$	Risk due to inhalation of air (unitless)	
C_{Air}	Concentration of contaminant in air (mg/m^3)	Calculated (see Table M-1.1)
B_{ri}	Breathing rate (m^3/d)	Exposure parameter (see Appendix G)
E_{di}	Exposure duration (yr)	Exposure parameter (see Appendix G)
E_{fi}	Exposure frequency (d/yr)	Exposure parameter (see Appendix G)
BW	Body weight (kg)	Exposure parameter (see Appendix G)
CSF_{Inhal}	Inhalation cancer slope factor $(mg/kg\text{-}d)^{-1}$	Health Benchmark (see Appendix Q)
AT	Averaging time (yr)	Exposure parameter (see Appendix G)
365	Conversion factor (d/yr)	

Description
These equations calculate the inhalation cancer slope factor from the unit risk factor and the inhalation cancer risk for individual constituents using the cancer slope factor.

U.S. EPA, 1997b.

Table M-6.3. Hazard Quotient Due to Oral Ingestion

$$HQ_{Oral} = \frac{I}{RfD}$$

Parameter	Description	Input Values
HQ_{Oral}	Hazard quotient due to oral ingestion (unitless)	
I	Intake rate (mg/kg-d)	Calculated (see Tables M-5.1-M-5.5)
RfD	Reference dose (mg/kg-d)	Health benchmark (see Appendix Q)

Description

This equation calculates the hazard quotient for indirect exposure to noncarcinogenic chemicals.

U.S. EPA, 1998b.

Table M-6.4. Hazard Quotient Due to Inhalation of Air

$$HQ_{Air} = \frac{C_{Air}}{RfC}$$

Parameter	Description	Input Values
HQ_{Air}	Hazard quotient due to inhalation of air (unitless)	
C_{Air}	Concentration in air (mg/m^3)	Calculated (see Table M-1.1)
RfC	Reference concentration (mg/m^3)	Health benchmark (see Appendix G)

Description

This equation calculates the inhalation hazard quotient for individual constituents.

U.S. EPA, 1998b.

References

U.S. EPA (Environmental Protection Agency). 1997a. *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions.* NCEA-0238. Update to *Methodology for Assessing Health Risks Associated with Indirect Exposure to Compustor Emissions*, EPA/600/6-90/003. National Center for Assessment, U.S. Environmental Protection Agency, Cincinnati, Ohio.

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U.S. EPA (Environmental Protection Agency). 1998a. *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities, Volume One*. EPA-530-D-98-001A. Office of Solid Waste and Emergency Response, Washington, DC.

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Appendix N

Air Dispersion and Deposition Modeling

Appendix N

Air Dispersion and Deposition Modeling

N.1 Introduction

Air dispersion modeling was conducted with EPA's Industrial Source Complex Short Term, Version 3 (ISCST3 - Dated 99155, U.S. EPA, 1999a). In this analysis, ISCST3 was used to estimate

- Air concentration of vapors
- Wet deposition of vapors
- Air concentration of particulates
- Wet deposition of particles
- Dry deposition of particles.

Dry deposition of vapors was calculated using a step external to the ISCST3 model because chemical-specific dry deposition modeling within ISCST3 was precluded by schedule considerations. Dry deposition of vapor was calculated using a dry deposition algorithm for particles (from the ISCST user's manual) that multiplies the vapor air concentration by a default deposition velocity.

The ISCST3 model and meteorological preprocessor, PCRAMMET, and related user's guides can be accessed and downloaded through the Internet from the Support Center for Regulatory Air Models (SCRAM) web page (http://www.epa.gov/scram001). The SCRAM is part of the EPA OAQPS Technology Transfer Network (TTN).

This appendix describes

- Preprocessing meteorological data using PCRAMMET
- Selecting the ISCST3 area source model option (TOXICS)
- Details on the model inputs specified.

N.2 Processing Meteorological Data Using PCRAMMET

Five years of representative meteorological data were processed for this analysis using the PCRAMMET preprocessor (U.S.EPA, 1995c). The data gathered included surface data, upper air data, and precipitation data.

N.2.1 Surface Data

Hourly surface meteorological data used in air dispersion modeling are processed from the Solar and Meteorological Surface Observation Network (SAMSON) CD-ROM (U.S. DOC and U.S. DOE, 1993). The variables include: temperature, pressure, wind direction, windspeed, opaque cloud cover, ceiling height, current weather, and hourly precipitation.

A quality control (QC) check of the meteorological data sources showed that SAMSON precipitation data were not adequate. Long-term average precipitation amounts calculated from SAMSON fell significantly short of the long-term values provided in the international station meteorological climate summaries (USN, USAF, and DOC, 1992). Reliable daily precipitation totals were available from the Cooperative Summary of the Day CD-ROM (NCDC, ERL, and NWS, 1995). A program (PRECIP) was developed to disaggregate and distribute the daily data to an hourly basis to create the hourly time series data required for air modeling. Using the available SAMSON data as a template to identify hours when rain occurred at a station, PRECIP created a distribution of hours in which rain occurs over the meteorological period of record. When no precipitation data were available in SAMSON for a given day, PRECIP filled in the data according to the calculated distribution. When precipitation did exist for a given day, it was filled proportionately to those hours.

QC checks of PRECIP were performed in two ways. First, printouts of cooperative station data from selected stations were compared to the processed hourly meteorological files by randomly selecting several days throughout the year that contained different situations (e.g., zero precipitation, trace precipitation, measured amount). These numbers were compared to the totals from the matching day in the hourly meteorological file. A second QC effort focused on all stations that were processed. The annual sum of the cooperative station precipitation data was compared to the annual sum of the new hourly meteorological file using a program called RAINTOT. The precipitation amounts always proved to be within a few percent of one another.

N.2.2 Upper Air Data

Twice daily mixing height data were gathered from the Radiosonde Data of North America CD-ROM (NCDC, 1997).

N.2.3 Filling Missing Data

Missing surface data were identified using a program called SQAQC, which searched for incidents of missing data on the observation indicator, opaque cloud cover, temperature, station pressure, wind direction and speed, and ceiling height. Years that were missing 10 percent or more of the data were discarded (Atkinson and Lee, 1992). Verification (QC) checks were performed on the SQAQC program by applying it to station data where the missing data were known and by intentionally degrading surface meteorological files and then running SQAQC to detect the missing values.

Missing surface data were filled in by a program called METFIX. This program fills in up to 5 consecutive hours of data for cloud cover, ceiling height, temperature, pressure, wind direction, and windspeed. For single missing values, the program follows the objective procedures developed by Atkinson and Lee (1992). For two to five consecutive missing values, other rules were developed because the subjective methods provided by Atkinson and Lee (1992) rely on professional judgment and could not be programmed. The METFIX program flagged files where missing data exceeded five consecutive values. In the few cases where this occurred and the missing data did not constitute 10 percent of the file, they were filled manually according to procedures set forth in Atkinson and Lee (1992). If more than 10 percent of the data were missing, the station was discarded and another nearby station was selected to represent the site.

All upper air files were checked for missing data using a program called QAQC. QAQC produces a log file containing occurrences of missing mixing height. Verification (QC) checks were performed on the QAQC program by applying it to station data where the missing data were known and by intentionally degrading existing mixing height files and then running QAQC to detect the missing values.

Missing mixing heights were filled in by running the files through another program written to interpolate one to five consecutive missing values. According to Atkinson and Lee (1992), if there are one to five consecutive missing values, the values should be filled in subjectively using professional judgment. Again, programming these subjective procedures was not feasible, and the program used simple linear interpolation to fill in these values automatically. Atkinson and Lee (1992) was used to determine which files should be discarded (i.e., files missing more than five consecutive missing values or missing 10 percent or more of the data). After the missing mixing heights were filled in for all upper air files, they were checked once more for missing data using the QAQC program.

N.2.4 Using PCRAMMET

PCRAMMET is a preprocessor program that integrates surface and upper air meteorological data into an input file for ISCST3. PCRAMMET calculates hourly stability values from surface observations, interpolates hourly mixing height values from twice-daily upper air data, and calculates parameters for wet and dry deposition/depletion calculations. PCRAMMET output can be selected as unformatted or ASCII format (U.S. EPA, 1995c). ISCST3 requires that meteorological data be in ASCII format.

PCRAMMET input files were set up in an automated fashion. In addition to the surface and upper air data, PCRAMMET requires the input of the following parameters (U.S. EPA, 1995c):

- Mixing height data file name
- Hourly surface data file name

- Minimum Monin-Obukhov length (m)
- Anemometer height (m)
- Roughness length (m), surface meteorological station
- Roughness length (m), paint facility
- Noontime albedo
- Bowen ratio
- Anthropogenic heat flux (W/m^2)
- Fraction net radiation absorbed by the ground.

The surface and upper air data file names were based on the station numbers of the respective meteorological stations. Assignment of these was determined using a geographic information system (GIS), based on polygons drawn around each mixing height station.

Anemometer height was collected from the local climatic data summaries (NOAA, 1983). When anemometer height was not available, the station was assigned the most common anemometer height from the other stations. This value was 6.1 m.

Land use information is required for determining a number of PCRAMMET inputs. To obtain this information, a GIS was used to determine the land use within a 3-km radius around each meteorological station by using GIRAS spatial data with Anderson land use codes (Anderson et al., 1976). Table N-1 shows how the Anderson land use codes were related to PCRAMMET land use codes.

A weighted average, based on the land use percentages for a 3-km radius around each meteorological station, was used to calculate the Bowen ratio, minimum Monin-Obukhov length, the noontime albedo, the roughness height at the meteorological station, and the fraction of net radiation absorbed by the ground.

- The Bowen ratio is a measure of the amount of moisture at the surface around a meteorological station. The wetness of a location was determined based on the annual average precipitation amount. The range of values is provided in Table N-2 as a function of land use type, season, and moisture condition. For this analysis, the annual average values were applied.

- The minimum Monin-Obukhov length, a measure of the atmospheric stability at a meteorological station, was correlated with the land use classification, as shown in Table N-3.

- Noontime albedo values also were correlated with land use around a meteorological station, as shown in Table N-4.

- The surface roughness length is a measure of the height of obstacles to the wind flow. It is not equal to the physical dimensions of the obstacles but is generally proportional to them. Surface roughness length data are shown in Table N-5, along with their corresponding land use. The roughness height was assumed to be the same at the meteorological station and at the paint facility in order to avoid creating a separate meteorological input file for every facility modeled.

- During daytime hours, the heat flux into the ground is parameterized as a fraction of the net radiation incident on the ground. This fraction varies based on land use. A value of 0.15 was used for rural locations. Suburban and urban locations were given values of 0.22 and 0.27, respectively (U.S. EPA, 1995c).

Anthropogenic heat flux for a meteorological station can usually be neglected in areas outside of highly urbanized locations; however, in areas with high population densities or energy use, such as an industrial facility, this flux may not always be negligible (U.S. EPA, 1995c). For this analysis, anthropogenic heat flux was assumed to be zero for all meteorological stations because little information was available to assume any anthropogenic heat flux value for most locations.

Table N-1. Relation Between Anderson Land Use Codes and PCRAMMET Land Use Codes

Anderson Code and Description[a]		RAMMET Type and Description[b]	
51	Streams and canals	1	Water surface
52	Lakes	1	Water surface
53	Reservoirs	1	Water surface
54	Bays and estuaries	1	Water surface
41	Deciduous forest land	2	Deciduous forest
61	Forested wetland	2	Deciduous forest
42	Evergreen forest land	3	Conifuerous forest
43	Mixed forest land	4	Mixed forest
62	Nonforested wetland	5	Swamp (nonforested)
84	Wet tundra	5	Swamp (nonforested)
21	Cropland and pasture	6	Agricultural
22	Orchards-groves-vineyards-nurseries-ornamental	6	Agricultural
23	Confined feeding operations	6	Agricultural
24	Other agricultural land	6	Agricultural
31	Herbaceous rangeland	7	Rangeland (grassland)
32	Shrub and brush rangeland	7	Rangeland (grassland)

(continued)

Table N-1. (continued)

Anderson Code and Description[a]		RAMMET Type and Description[b]	
33	Mixed rangeland	7	Rangeland (grassland)
11	Residential	9	Urban
12	Commercial and services	9	Urban
13	Industrial	9	Urban
14	Transportation-communication-utilities	9	Urban
15	Industrial and commercial complexes	9	Urban
16	Mixed urban or built-up land	9	Urban
17	Other urban or built-up land	9	Urban
71	Dry salt flats	10	Desert shrubland
72	Beaches	10	Desert shrubland
73	Sandy areas not beaches	10	Desert shrubland
74	Bare exposed rock	10	Desert shrubland
75	Strip mines-quarries-gravel pits	10	Desert shrubland
76	Transitional areas	10	Desert shrubland
81	Shrub and brush tundra	10	Desert shrubland
82	Herbaceous tundra	10	Desert shrubland
83	Bare ground	10	Desert shrubland
85	Mixed tundra	10	Desert shrubland
91	Perennial snowfields	10	Desert shrubland
92	Glaciers	10	Desert shrubland

[a] Anderson codes from Anderson et al. (1976).
[b] RAMMET codes from U.S. EPA (1995c).

Table N-2. Daytime Bowen Ratio by Land Use and Season

Land Use Type	Spring			Summer			Autumn			Winter			Annual Average		
	Dry	Wet	Avg.	Dry	Wet	Avg.	Dry	Wet	Avg.	Dry	Wet	Avg.	Dry	Wet	Avg.
Water surface	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	2.0	0.3	1.5	0.575	0.15	0.45
Deciduous forest	1.5	0.3	0.7	0.6	0.2	0.3	2.0	0.4	1.0	2.0	0.5	1.5	1.53	0.35	0.875
Coniferous forest	1.5	0.3	0.7	0.6	0.2	0.3	1.5	0.3	0.8	2.0	0.3	1.5	1.4	0.275	0.825
Swamp	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	2.0	0.5	1.5	0.65	0.2	0.45
Cultivated land (agricultural)	1.0	0.2	0.3	1.5	0.3	0.5	2.0	0.4	0.7	2.0	0.5	1.5	1.63	0.35	0.75
Grassland	1.0	0.3	0.4	2.0	0.4	0.8	2.0	0.5	1.0	2.0	0.5	1.5	1.75	0.425	0.825
Urban	2.0	0.5	1.0	4.0	1.0	2.0	4.0	1.0	2.0	2.0	0.5	1.5	3.0	0.75	1.6
Desert shrub land	5.0	1.0	3.0	6.0	5.0	4.0	10.0	2.0	6.0	10.0	2.0	6.0	7.75	2.5	4.75

Source: U.S. EPA, 1995c. Averages computed for this effort.

Table N-3. Minimum Monin-Obukhov Length (Stable Conditions)

Urban Land Use Classification	Length (m)
Agriculture (open)	2
Residential	25
Compact residential/industrial	50
Commercial (19-40 story buildings) (> 40 story buildings)	100 150

Source: U.S. EPA, 1995c.

Table N-4. Albedo Values of Natural Ground Covers for Land Use Types and Seasons

Land Use Type	Spring	Summer	Autumn	Winter	Annual Average
Water surface	0.12	0.1	0.14	0.2	0.14
Deciduous forest	0.12	0.12	0.12	0.5	0.22
Coniferous forest	0.12	0.12	0.12	0.35	0.18
Swamp	0.12	0.14	0.16	0.3	0.18
Cultivated land (agricultural)	0.14	0.2	0.18	0.6	0.28
Grassland	0.18	0.18	0.20	0.6	0.29
Urban	0.14	0.16	0.18	0.35	0.21
Desert shrub land	0.3	0.28	0.28	0.45	0.33

Source: U.S. EPA, 1995c. Average values computed for this analysis.

Table N-5. Surface Roughness Length for Land Use Types and Seasons (meters)

Land Use Type	Spring	Summer	Autumn	Winter	Annual Average
Water surface	0.0001	0.0001	0.0001	0.0001	0.0001
Deciduous forest	1.0	1.3	0.8	0.5	0.9
Coniferous forest	1.3	1.3	1.3	1.3	1.3
Swamp	0.2	0.2	0.2	0.05	0.16
Cultivated land (agricultural)	0.03	0.2	0.05	0.01	0.07
Grassland	0.05	0.2	0.01	0.001	0.04
Urban	1.0	1.0	1.0	1.0	1.0
Desert shrubland	0.3	0.3	0.3	0.15	0.26

Source: U.S. EPA, 1995c. Average values computed for this analysis.

N.3 Selecting the ISCST3 Area Source Model Option (TOXICS)

The most recent version of ISCST3 (version 99155, U.S. EPA, 1999a) allows the user to select a regulatory default option or to select the TOXICS option. Given the benefit of reduced run-times, the TOXICS options was applied in this analysis. A sensitivity analysis was conducted that compares the regulatory option to the TOXICS mode.

N.3.1 Overview of Area Source Model Options

The ISCST3's area source model is based on a numerical integration over the area in the upwind and crosswind directions of the Gaussian point source plume formula. The integral in the lateral (i.e., crosswind or y) direction is solved analytically using the complementary error function. The integral in the longitudinal (i.e., upwind or x) direction is approximated using numerical methods.

Two numerical integration techniques are used in the latest version of the ISCST3 model (version 99155). In the Regulatory Default mode, the ISCST3 model used a Romberg numerical integration to estimate the area source impacts. When the nonregulatory default TOXICS option is specified, a more computationally efficient two-point Gaussian Quadrature routine is used along with the Romberg technique to improve model run-time.

For the TOXICS option, a two-point Gaussian Quadrature routine is used to approximate the numerical integral for cases where the receptor location is not within or adjacent to the area source. If the receptor is located within or adjacent to the area source, then the Romberg routine and the two-point Gaussian Quadrature routine may both be used depending upon the relationship between the side of source and the receptor. For receptors that are located several source-widths downwind of an area source, a virtual point source approximation is used.

When area sources are modeled with dry depletion, the TOXICS option also allows the user to specify the Areadplt option, which applies a single effective dry depletion factor to the undepleted value calculated for the area source, rather than applying the numerical integration for depletion within the area source integral. Therefore, this option will significantly reduce the run-time.

The results of the wind tunnel study performed by EPA (1992) were used to examine the ISCST3 model's Romberg numerical integration algorithm. The comparison has shown that the Romberg algorithm performs very well in terms of efficiency and in terms of the reasonableness of the results (U.S. EPA, 1992). However, it takes a significant amount of time to execute for large area sources. In order to improve model run-times, the TOXICS option was added to the area source model. It should be noted that the TOXICS option has never been tested against measured data. However, it is generally assumed that the model results generally agree well between the Regulatory Default option and the TOXICS option. A sensitivity analysis was conducted to evaluate the validity of this assumption.

Table N-6. Source Scenarios and Dimensions

Source Scenario	Source Area (m^2)	Source Height (m)
Scenario 1: Large, Ground-Level Square Shape Area Source	1,000,000	0
Scenario 2: Small, Ground-Level Square Shape Area Source	10,000	0
Scenario 3: Large, Elevated Square Shape Area Source	1,000,000	5
Scenario 4: Small, Elevated Square Shape Area Source	10,000	5

N.3.2 Sensitivity Analysis

An evaluation was conducted to determine the accuracy and the speed of the TOXICS option against the Regulatory Default option. In the evaluation, one large and one small square area source were modeled. For each area source, two source heights (i.e., ground level and 5 m above the ground) were used. Source scenarios and dimensions used in the analysis are shown in Table N-6.

N.3.2.1 Receptor. The receptor points were placed on 0-, 50-, 100-, 250-, 500-, and 1,000-m receptor squares starting from the edge of the source, with 16 receptor points placed on each square. The first receptor square (i.e., 0 m) was placed at the edge of the unit.

N.3.2.2 Meteorology. One full year (1990) of meteorological data from Houston, Texas, were used in the analysis. The surface roughness length of 0.7 m was used for the application site.

N.3.2.3 Model Run. The ISCST3 model was run for particles and vapors using the four source scenarios to compare the differences between the three modeling options (Regulatory Default, Toxics, and Toxics/Areadplt). Two average particle sizes (i.e., 5 and 20 μm) were used in the particle runs. For the vapor runs, vapors were modeled as fine particles (average diameter of 0.1 μm). For particle runs, annual average air concentration and dry deposition rate at each receptor location were recorded for comparison. Wet deposition was not selected since annual average wet deposition rate is usually only a small percentage of dry deposition rate. For the vapor runs, annual average air concentration and wet deposition rate at each receptor location were modeled since dry deposition of vapor is not an option for the Regulatory Default option. The dry depletion option was used for all the particle runs and wet depletion was used for vapors.

N.3.3 Results and Comparison

N.3.3.1 Run-time. Table N-7 presents model run-time for each particle run. The comparison indicates that the TOXICS option can save a significant amount of run-time compared to the Regulatory Default option.

Table N-7. Model Run-Time (Particles) (minutes)

Source Scenario	Regulatory Default	Toxics	Toxics Areadplt
Scenario 1: Large, Ground-Level Square Shape Area Source	3,314	89	7
Scenario 2: Small, Ground-Level Square Shape Area Source	217	10	2
Scenario 3: Large, Elevated Square Shape Area Source	135	8	2
Scenario 4: Small, Elevated Square Shape Area Source	38	4	1

N.3.3.2 <u>Results</u>. For each source scenario, model results from the three options (Regulatory Default, TOXICS, TOXICS/Areadplt) were compared.

The maximum particle concentrations agree very well between the Regulatory Default option and the TOXICS option. The differences in dry deposition rate are also very small between the two options for receptors located close to the area source. The differences increase with the increasing downwind distance. At 1,000 m from the area source, the maximum dry deposition rate for the TOXICS option is approximately three times that of the deposition rate for the Regulatory Default option for the large, ground-level area source (source scenario 1). For the other three source scenarios, the differences in dry deposition rates are smaller than the differences for scenario 1.

In general, air concentrations match well between the Regulatory Default option and the Areadplt option. As the downwind distances increase, the ratios of the maximum dry deposition rates between the Areadplt option and the Regulatory Default option increase from as low as 0.19 to as high as 3.2. Therefore, it is difficult to judge whether the Areadplt option is less or more conservative than the Regulatory Default option.

The maximum vapor (fine particle) concentrations and wet deposition rates match very well between the Regulatory Default option and the TOXICS option for all the four scenarios at all receptor distances. The differences in air concentrations are small between the Regulatory Default option and the Areadplt option. The ratios of the maximum dry deposition rates between the Areadplt option and the Regulatory Default option are between 1 and 2.

Based on the reduced run-times, the TOXICS option was selected for this analysis. As discussed above, maximum particle concentrations, maximum vapor (fine particle) concentrations, and maximum vapor wet deposition rates agree very well between the Regulatory Default option and the TOXICS option. However, the TOXICS option, in comparison to the Regulatory Default option, may tend to overpredict dry deposition of particles for receptors placed beyond 1,000 m from the edge of large, ground-level area sources.

N.4 Preparing ISCST3 Input Files

Two types of input files are required to run ISCST3, the runstream file and the meteorological file. The runstream file is an ASCII file that contains the model option settings, source parameters, and receptor locations. The meteorological file contains hourly values of windspeed, wind direction, stability class, mixing height, ambient air temperature, and precipitation type and amount.

N.4.1 ISCST Runstream Files

The ISCST3 runstream file is composed of six pathways that drive different model functions. They are the Control Pathway, Source Pathway, Receptor Pathway, Meteorology Pathway, Terrain Grid Pathway, and Output Pathway. The options selected in each of these pathways is discussed below. The Terrain Grid Pathway is not discussed since it is only used with point sources (i.e., for facilities with stacks).

N.4.1.1 Control Pathway. Under the control pathway, the user specifies keywords that determine whether the model will calculate air concentrations or deposition rates. In addition, modeling options that are to be applied as part of these calculations are specified. Keywords used in the control pathway include MODELOPT (controls modeling options), AVERTIME (identifies averaging period to be calculated for the run), and POLLUTID (identifies the type of pollutant being modeled).

The MODELOPT keyword indicates the model options selected. For this assessment, these options were set to process air concentration (CONC) of particles and vapors, dry deposition (DDEP) of particles, and wet deposition (WDEP) of particles and vapors. Dry (DRYDPLT) and wet depletion (WETDPLT) of particles and wet depletion of vapors were selected. Default regulatory options were not selected; instead, the model was run in TOXICS mode, which optimizes the processing time by using a more computational efficient two-point Gaussian Quadrature approach along with the regulatory Romberg routine.

Another modeling option that is controlled by the MODELOPT keyword is whether the model is run in rural or urban mode. This distinction is based on the land use within a 3-km radius of the emission source. These models differ with respect to wind profile exponent and temperature gradients. Unless the site is located in a heavily metropolitan area, the rural option is generally more appropriate. Because the types of WMUs being assessed are typically in nonurban areas, the rural option was used in this analysis.

The POLLUTID keyword was set to “OTHER” to allow various pollutants to be considered with one general model run.

AVERTIME keyword was set to “24 Month Annual” to generate results for three different averaging periods: 24-h (daily) averages, monthly averages, and annual averages. Annual averaging time was selected because human and ecological risk benchmarks are based on long-term exposure. Twenty-four hour and monthly deposition and average air concentrations were generated as input to the acute and subchronic analyses, respectively.

N.4.1.2 Source Pathway. The source pathway is used to set various source characteristics, such as emission rate, release height, and source dimensions. In this analysis, an area source was modeled for all WMUs. Landfills and surface impoundments were modeled as ground-level area sources (height of zero). Tanks were modeled as elevated area sources with an initial vertical dimension of the plume equal to the source height divided by 2.15 (U.S. EPA, 1995a). Sources were all considered to be circular in shape and centered on the origin (0,0) to minimize error due to site orientation. The model treats circular sources as 20-sided polygons. For the tank modeling, a unit emission of 1 g/m^2-s was applied. For surface impoundments and landfills, a unit emission rate of 1 µg/m^2-s was used for sources larger than 5,000 m^2 and 1 mg/m^2-s was used for sources 5,000 m^2 and smaller. It was necessary to apply smaller unit emission rates for landfills and surface impoundments because of their large surface areas. That is, the larger surface areas result in output values that cannot be accommodated by the fixed width of the ISCST3 output table. To compensate for this adjustment, the results obtained for sources modeled with a unit emission rate of 1 µg/m^2-s were multiplied by 1E+06 and those modeled with a unit emission of 1 mg/m^2-s were multiplied by 1E+03.

When particles are being modeled, the source pathway contains particle size information and scavenging coefficients. These data are used in determining deposition and depletion. Because there was a concern that the emission control dust may contain very small particle sizes that may not be adequately represented using the default distribution, a sensitivity analysis was conducted to determine how sensitive the air dispersion model was to changing the particle size distribution for the risk assessment. The sensitivity analysis focused on determining how sensitive EPA's ISCST3 air dispersion model was to varying the particle size distribution of emitted particles. Based on the results of the sensitivity analysis, it was determined that the air concentration was not sensitive to changing the particle size distribution. It was also determined that changing the particle size distribution to reflect smaller particle sizes was not conservative in terms of deposition rates (Birak and Marimpietri, 2000).

As shown in Table N-8, four particle size categories less than and equal to 30 µm in diameter (PM_{30}) were modeled. These categories represent the size distribution of the particulate matter that can be released as fugitive particulate emissions from the landfill unit. This distribution was derived from the AP-42 (U.S. EPA, 1995b) distribution for wind erosion from an industrial field. Based on the sensitivity analysis, it was concluded that the carcinogenic risks and noncancer hazards would not be underestimated for emission control dust by using the default particle size distribution.

ISCST3 requires the user to input two scavenging coefficients for each particle size category: one for liquid and one for frozen precipitation. Wet scavenging coefficients for particles were taken from ISC3 User's Guide (U.S. EPA, 1995a) as shown in Figure N-1. They were assigned based on the size of the particles. The frozen scavenging coefficient was assumed to be one-third of the liquid coefficient (U.S. EPA, 1998).

For vapors, gas scavenging coefficients are required to be specified in the source pathway. A vapor scavenging rate coefficient of 1.7E-04 was used for all WMUs. This value was obtained by using a 0.1-μm particle as a surrogate for vapor and using the corresponding

Table N-8. Particle Size and Wet Scavenging Coefficients Used in Dispersion Modeling

Particle Size Category	Mean Particle Diameter Modeled (μm)	Mass Fraction	Wet Scavenging Rate Coefficient (h/mm-s)
30 - 15 µm	22.5	0.4	6.7E-04
15 - 10 µm	12.5	0.1	6.7E-04
10 - 2.5 µm	6.3	0.3	4.N-04
< 2.5 µm	1.3	0.2	6.0E-05

coefficient shown in Figure N-1. It was assumed that the frozen scavenging coefficient was one-third of the liquid scavenging coefficient (U.S. EPA, 1998).

N.4.1.3 __Receptor Pathway__. The receptor pathway defines the receptor grid used in the analysis. ISCST3 is capable of modeling concentrations and depositions to Cartesian grid receptors, polar grid receptors, or discrete receptors. For this analysis, rings of receptors were placed in a polar grid surrounding the source. Receptors were placed along 16 radials in equally spaced directions. Receptor ring placement started at the edge of the unit (0 m) and extended out to 2,000 m from the edge of the unit. The number of rings modeled varied depending on the WMU type. This variation was due in part to considerable run-times for particle runs. For tanks, it was necessary to include multiple rings close to the unit to ensure that the maximum impact was not underestimated due to elevated release height.

The following identifies the receptor distances from the edge of the WMU considered for each unit type.[1]

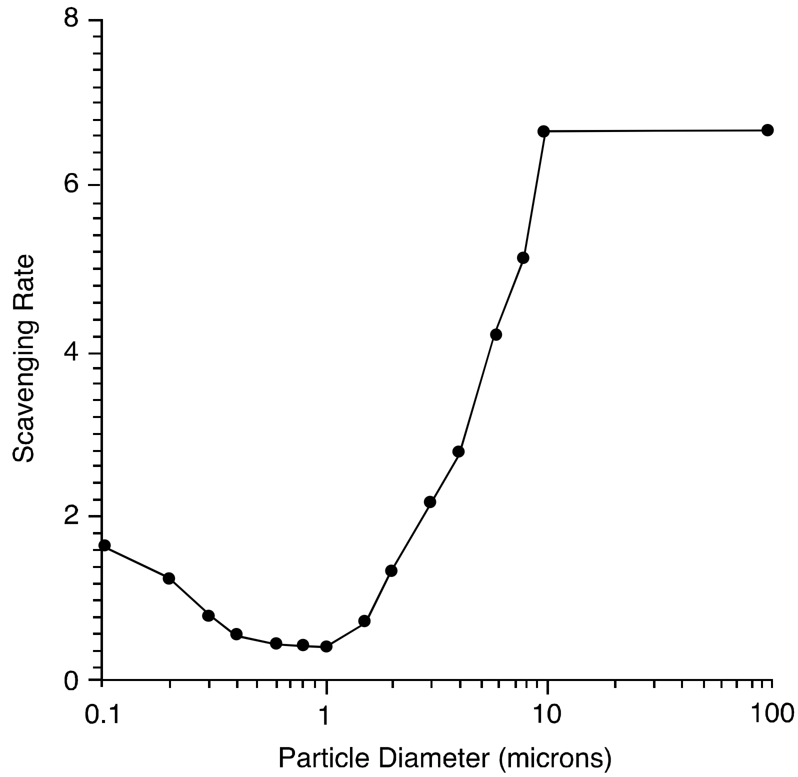
Landfills: 0, 50, 150, 250, 350, 450, 550, 1,000, 1,500, and 2,000 m

Surface Impoundments: 0, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 1,000, 1,500, and 2,000 m

Tanks: 0, 0.4, 2, 10, 50, 150, 250, 350, 450, 550, 1,000, 1,500, and 2,000 m.

N.4.1.4 __Meteorological Pathway__. The meteorological pathway provides information about the meteorological input data, including file name, anemometer height at the surface station, meteorological station identification numbers, and identification of the initial year of data in the data set.

[1] It should be noted that in some initial landfill model runs, additional rings were modeled. However, to improve run-time, it was necessary to reduce the number of rings to include only the distances specified above for landfills.



Source: U.S. EPA, 1995a, citing Jindal and Heinold, 1991.

Figure N-1. Wet scavenging rate coefficient as a function of particle size.

In this analysis, 5 years of data were used at 49 meteorological stations throughout the country. Section 4.0 discusses how specific surface and upper air stations were selected.

N.4.1.5 <u>Output Pathway</u>. The ISCST3 model output was formatted to fit the needs of subsequent indirect exposure modeling procedures. Plotter files, which contain receptor location and associated air quality data, best fit these subsequent modeling requirements. For particle runs (completed for landfills only), each meteorological location/landfill surface area combination generated three plotter files. These plotter files correspond to the three averaging times modeled, annual, monthly, and daily or 24-h. For each averaging period, the files provide the x and y coordinates of each receptor, the average concentration, and the wet and dry deposition estimates calculated for each receptor. Similarly, vapor runs resulted in three plotter files that also corresponded to the three averaging periods. Vapor runs were completed for all WMU type/meteorological location/area-height combinations. The files produced by the vapor runs are similar in format to the particle files except that they contain a dry deposition column.

N.4.1.6 <u>Meteorological Files</u>. The meteorological file is generated using the meteorological preprocessor PCRAMMET (U.S. EPA, 1995c). The preprocessor pairs hourly surface observations with upper air soundings. For each of the 49 meteorological stations modeled, 5 years of surface and upper air data were used. The preprocessor creates a file in binary format that contains hourly wind speed, wind direction, atmospheric stability class, temperature, and mixing height. Land use data also were required by PCRAMMET in the vicinity of each meteorological station to derive air model inputs such as Bowen ratio, surface roughness height, minimum Monin-Obukhov length, noontime albedo, and the fraction of net radiation absorbed by the ground.

N.4 References

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Appendix O

Groundwater Modeling Parameters

Table O-1 Groundwater Model Variables

Table O-2 Correlated Empirical Distributions

Table O-3 Empirical Distributions for Groundwater Modeling

Table O-4 Organic Constituent Surrogate Groups

Appendix O

Groundwater Modeling Parameters

The groundwater pathway was modeled to determine the residential drinking water well concentrations resulting from a release of waste constituents from the WMU. The transport of leachate from the WMU through the unsaturated and saturated zones is quantitatively evaluated using EPACMTP (U.S. EPA, 1997a, 1997b). This appendix presents the input values and the distributions used in modeling the groundwater pathway using EPACMTP. Tables O-1 through O-3 present the groundwater parameters used, the type of parameters (i.e., whether the parameter is considered to be constant or variable), and the source of the data. Table O-2 presents interdependent (i.e., correlated) groundwater parameters that are based on actual site data (Newell et al., 1989). The value of “-999" was inserted into Table O-2 when site data were unavailable. The value of “-999" triggers the model to replace the unavailable data with another data point derived from other data contained in the complete dataset.

Groundwater modeling of the organic constituents was based on modeling of surrogate chemical groups instead of individual organic constituents in order to reduce the number of model runs required. Six surrogate chemical groups, plus one special chemical case, were identified based on the chemical properties of each constituent. Specifically, each of the organic constituents was categorized in accordance with the organic carbon partition coefficient (K_{oc}) and the hydrolysis constant (K_h or lambda) (Table O-4). The K_{oc}s and lambdas were assigned a value as follows:

K_{oc}	Group	Lamda	Group
0	1	0	1
<100	2	<0.0001	2
<1000	3	<0.10	3
<2000	4	<0.20	4
>2000	5	>0.20	5

As shown in Table O-4, the constituents in bold print were modeled as surrogates, including ethylene glycol, chloroform, acrylonitrile, and tetrachloroethylene. Pentachlorophenol was a special case in that it is an ionizing organic compound and its K_{oc} changes as a function of pH. Therefore, it was inappropriate to assess it as part of a surrogate group. The two surrogate groups represented by dibutylphthalate and ethylbenzene were screened from the groundwater analysis because the leachate concentration predicted by the source partition modeling was zero at the 90th percentile level.

Table O-1. Groundwater Model Variables

Variable ID	Parameter	Units	Type	Value	Comments	Reference
Aquifer						
ANIST	Anisotropy ratio	Unitless	Constant	1	No anisotropy	U.S. EPA, 1997a
PH	Groundwater pH	std. Units	Constant	Site-specific	Assumed equal to average soil pH for 20-mi radius around location	See Appendix I.2
TEMP	Groundwater temperature	DegreesC	Constant	Site-specific	Groundwater temperature map; average for 20-mi radius around location	van der Leeden, 1990
BULKD	Bulk density	g/cm3	Derived	Calculated by EPACMTP	Derived from porosity	U.S. EPA, 1997a
YWELL(I)	Distance from plume centerline to well	m	Derived	Calculated by EPACMTP	Derived from radial distance (R) and angle to the well	U.S. EPA, 1997a
POR	Effective porosity	Unitless	Derived	Calculated by EPACMTP	Derived from particle diameter	U.S. EPA, 1997a
VXCS	Groundwater seepage velocity	m/yr	Derived	Calculated by EPACMTP	Derived from conductivity and gradient	U.S. EPA, 1997a
XWELL(I)	Longitudinal distance to well	m	Derived	Calculated by EPACMTP	Derived from radial distance (R) and angle to the well	U.S. EPA, 1997a
RETARD(I)	Retardation coefficient	Unitless	Derived	Calculated by EPACMTP	Derived from bulk density, Kd, and porosity	U.S. EPA, 1997a
AT	Transverse dispersivity	m	Derived	Calculated by EPACMTP	Derived from longitudinal dispersivity	U.S. EPA, 1997a
AV	Vertical dispersivity	m	Derived	Calculated by EPACMTP	Derived from longitudinal dispersivity	U.S. EPA, 1997a
IGWR	Aquifer code	Integer	Empirical	Site-specific	Derived using state-specific aquifer maps	See Appendix I.2
DIAM	Avg. particle diameter	cm	Empirical	Randomly selected from national distribution		See attached Table O-3
ALPHA(AL)	Longitudinal dispersivity (aquifer)	m	Empirical	Calculated from a national distribution and radial distance to well (R)		See attached Table O-3
RADIS(I)	Radial distance to well (R)	m	Empirical	Randomly selected from national distribution	EPA OSW survey of landfills	See attached Table O-3
ZB	Aquifer thickness	m	Empirical correlated	Aquifer-specifc	Randomly selected based on aquifer code (IGWR) using EPACMTP	See attached Table O-2
GRADNT	Hydraulic gradient	m/m	Empirical correlated	Aquifer-specifc	Randomly selected based on aquifer code (IGWR) using EPACMTP	See attached Table O-2
XKX	Longitudinal hydraulic conductivity (K)	m/yr	Empirical correlated	Aquifer-specifc	Randomly selected based on aquifer code (IGWR) using EPACMTP	See attached Table O-2
FOC	Fraction organic carbon (FOC)	g/g	Johnson SB	Randomly selected from national distribution	Mean = 0.000432; stdev = 0.0456; min = 0; max = 0.0638	U.S. EPA, 1997a; U.S. EPA, 2000
ANGLE(I)	Angle of well off plume centerline	Degrees	Uniform	Randomly selected from uniform distribution within plume		U.S. EPA, 1997a

Table O-1. Groundwater Model Variables

Variable ID	Parameter	Units	Type	Value	Comments	Reference
ZWELL(I)	Depth of well below water tabl	Fraction	Uniform	Randomly selected from uniform distr. within ZB or within upper 10 m of aquifer if ZB>10 m		U.S. EPA, 1997a
Chemical						
AHYDR(I)	2nd order acid hydrolysis rate	1/yr	Constant	Chemical-specific	Organics only	Kollig, 1993
BHYDR(I)	2nd order base hydrolysis rate	1/yr	Constant	Chemical-specific	Organics only	Kollig, 1993
BIOU	Biodegradation rate	1/yr	Constant	0	No biodegradation	
UFEXP(I)	Freundlich isotherm exponent	Unitless	Constant	1	Linear sorption for organics and metals	
CZERO	Leachate concentration (maximum 9-yr average)	mg/L	Constant	1,000,000	Assumed 100% concentration since unknown	
DSTAR	Molecular diffusion coefficient	m2/yr	Constant	0	NA	
NHYDR(I)	Neutral hydrolysis rate	1/yr	Constant	Chemical-specific	Organics only	Kollig, 1993
KOC(I)	Organic carbon distribution coefficient (KOC)	mL/g	Constant	Chemical-specific	Organics only; NA for metals, so set equal to zero	Kollig, 1993
RTEMP	Reference temperature	C	Constant	Chemical-specific	Organics only; NA for metals, so set equal to zero	Kollig, 1993
UCLAM(I)	Chemical decay rate	1/yr	Derived	Calculated by EPACMTP	Derived from dissolved and sorbed rates for organics only	U.S. EPA, 1997a
RLAM1(I)	Dissolved hydrolysis rate	1/yr	Derived	Calculated by EPACMTP	Derived from rate constants for organics only	U.S. EPA, 1997a
FSRATIO	Finite source ratio (CW/CL)	L/kg	Derived	Calculated by the source model	Ratio of concentration in the waste to concentration in the leachage	
RLAM2(I)	Sorbed hydrolysis rate	1/yr	Derived	Calculated by EPACMTP	Derived from rate constants for organics only	U.S. EPA, 1997a
UFCOF(I)	Freundlich isotherm coefficient (Kd)	cm3/g	Derived, empirical, log uniform, or pH-based isotherm	Chemical-specific	Function of KOC and POM for organics; choser from distributions developed using literature values for metals, pH-based value for pentachlorophenol	
Exposure						
CARC(I)	Groundwater averaging time	yr	Constant	Constant value of 9 yr	Used to represent long-term concentration for chronic exposure	

Table O-1. Groundwater Model Variables

Variable ID	Parameter	Units	Type	Value	Comments	Reference
Meteorological						
RECH	Recharge rate	m/yr	Derived	Site-specific	Dervied using the general soil column model	See Appendix I.2
METSTA	Meteorological station	Unitless	Empirical	Location chosen for 10,000 iterations using a weighted distribution of 49 me stations	Locations were weighted based on the volume of paint manufactured in each state divided among the met stations chosen in a given state.	
Vadose						
ALPHA	Moisture retention parameter (a)	1/cm	Constant	Site-specific	Mean value assigned for a given soil texture (i.e., soil index)	See Appendix I.2
BETA	Moisture retention parameter (b)	Unitless	Constant	Site-specific	Mean value assigned for a given soil texture (i.e., soil index)	See Appendix I.2
POM	Percent organic matter (POM)	%	Constant	Site-specific	Mean value assigned for a given soil texture	See Appendix I.2
WCR	Residual water content	L/L	Constant	Site-specific	Mean value assigned for a given soil texture (i.e., soil index)	See Appendix I.2
SATK	Saturated hydraulic conductivity	cm/hr	Constant	Site-specific	Mean value selected for a given soil texture (i.e. soil index)	See Appendix I.2
WCS	Saturated water content	L/L	Constant	Site-specific	Mean value assigned for a given soil texture (i.e., soil index)	See Appendix I.2
RHOB	Soil bulk density	g/cm3	Constant	Site-specific	Derived from saturated water content	See Appendix I.2
SOILID	Soil index	Integer	Constant	Site-specific	Average type within a 20-mi radius	See Appendix I.2
DISPR	Longitudinal dispersivity (vadose)	m	Derived	Calculated by EPACMTP	Derived from unsaturated zone thickness	U.S. EPA, 1997a
DSOIL	Unsaturated zone thickness	m	Empirical correlated	Aquifer-specifc	Randomly selected based on aquifer code (IGWR)	See Table O-2

Table O-1. Groundwater Model Variables

Variable ID	Parameter	Units	Type	Value	Comments	Reference
WMU						
PWS	Total waste volume (over 30 yr)	m3	Constant	WMU-specific	Chosen based on WMU ID for a given iteration. yearly volume times 30-yr active life of LF (i.e. capacity)	See Appendix E
CTDENS	Waste density	g/cm3	Constant	1.8 g/cm3 wet	Derived based on dry bulk density for waste assuming 50% of pore spaces are filled with moisture	U.S. EPA, 1997a
AREA	WMU area	m2	Constant	WMU-specific	Chosen based on WMU ID for a given iteration	See Appendix E
TSOURCE	Duration of leaching period (for LF only)	yr	Derived	Calculated by EPACMTP	Leaching continues until all constituent mass is depleted	U.S. EPA, 1997a
SINFIL	Infiltration rate	m/yr	Derived	Calculated by the source model	Separate value for each iteration	U.S. EPA, 1997a
XY	WMU length	m	Derived	Calculated by EPACMTP	Square root of area	U.S. EPA, 1997a
YD	WMU width	m	Derived	Calculated by EPACMTP	Square root of area	U.S. EPA, 1997a

Table O-2. Correlated Empirical Distributions

Aquifer Code	Longitudinal Hydraulic Conductivity Aquifer (m/yr)	Unsaturated Zone Thickness (m)	Aquifer Thickness (m)	Hydraulic Gradient (m/yr)	Notes
1	-999	25.9	-999	0.0166	
1	3.15	16.8	152	-999	
1	-999	15.2	15.2	-999	
1	-999	610	-999	0.0001	
1	-999	5.79	9.14	0.05	
1	946	4.57	-999	0.014	
1	1580	3.05	-999	0.014	
1	63.1	4.88	12.2	0.07	
1	3470	6.1	152	0.03	
1	28.4	2.04	9.14	0.01	
1	126	6.1	7.32	0.03	
1	15.8	3.81	32.9	0.09	
1	315	21.3	3.05	-999	
1	-999	6.1	6.1	0.000007	
1	11000	3.05	18.3	0.02	
1	94.6	1.83	4.27	0.04	
1	-999	1.22	9.14	0.01	
1	7570	1.52	3.05	0.000007	
1	6.31	0.914	6.1	0.038	
1	6.31	1.83	7.62	0.1	
1	31.5	6.1	-999	0.06	
1	31.5	0.305	6.1	0.005	
1	-999	9.14	152	0.008	
1	-8.52129	2.81441	3.76962	-3.97399	Mean
1	6.82319	1.07478	1.80348	-0.39418	Covariance
1	1.07478	0.8005	0.55257	0.4367	Covariance
1	1.80348	0.55257	1.1956	0.17788	Covariance
1	-0.39418	0.4367	0.17788	0.81424	Covariance
1	3.15	0.305	3.05	0.000007	Minimum
1	11000	610	152	0.81424	Maximum
2	63.1	6.1	22.9	0.08	
2	28.4	6.1	79.3	-999	
2	1890	76.5	-999	0.008	
2	5990	30.5	183	0.001	
2	315	65.5	45.7	0.0057	
2	31.5	15.2	21.3	0.1	
2	1580	174	30.5	-999	
2	315	5.97	3.6	-999	
2	22.1	12.2	10.7	0.028	
2	284	16.8	3.05	0.0032	
2	9.46	6.1	152	0.031	
2	221	9.14	-999	0.008	
2	3.15	3.96	4.57	0.01	
2	3.15	4.57	91.4	0.001	
2	2210	15.2	30.5	0.033	
2	11000	18.3	91.4	-999	
2	126	13.4	7.62	0.004	

Table O-2. Correlated Empirical Distributions

Aquifer Code	Longitudinal Hydraulic Conductivity Aquifer (m/yr)	Unsaturated Zone Thickness (m)	Aquifer Thickness (m)	Hydraulic Gradient (m/yr)	Notes
2	1330	6.1	21.3	0.005	
2	31500	1.83	3.05	-999	
2	-999	4.27	89	-999	
2	1890	53.6	6.1	0.043	
2	9780	18.3	30.5	0.012	
2	6.31	12.2	24.4	0.015	
2	3.15	12.2	12.2	0.025	
2	12.6	3.7	30	0.01	
2	22100000	9.14	1.52	1	
2	34700	12.2	4.57	0.008	
2	31500	15.2	6.1	0.05	
2	3.15	3.66	9.14	0.04	
2	315	9.14	21.3	0.005	
2	315	8.53	19	0.025	
2	-999	4.88	-999	-999	
2	-999	3.05	-999	0.024	
2	63.1	4.57	19.8	0.04	
2	189	6.1	61	0.023	
2	22100000	4.57	1.83	1	
2	-999	183	12.2	0.0004	
2	22.1	2.74	3.05	-999	
2	189	15.2	61	0.012	
2	11000	15.2	22.9	0.0005	
2	-999	3.66	18.3	-999	
2	63.1	8.23	518	0.007	
2	126	4.57	107	0.03	
2	-999	1.52	91.4	-999	
2	-7.68877	3.4698	4.2618	-4.42479	Mean
2	12.3279	1.32509	0.47331	-1.46902	Covariance
2	1.32509	0.54208	-0.01357	-0.1757	Covariance
2	0.47331	-0.01357	1.61831	-0.39626	Covariance
2	-1.46902	-0.1757	-0.39626	1.75145	Covariance
2	3.15	1.52	1.52	0.0004	Minimum
2	22100000	183	518	1	Maximum
3	25500	3.66	3.66	0.0009	
3	946	9.14	5.33	0.005	
3	1260	1.77	6.1	0.000000004	
3	28.4	6.1	-999	0.034	
3	3780	16.8	1.52	0.04	
3	2680	6.71	2.44	0.009	
3	31.5	9.45	-999	0.05	
3	-999	7.62	-999	0.01	
3	63.1	2.3	4.12	0.007	
3	6620	30.5	21.3	0.02	
3	126	3.06	15.2	0.01	
3	31.5	-999	-999	0.01	
3	8830	5.33	45.7	0.0005	

Table O-2. Correlated Empirical Distributions

Aquifer Code	Longitudinal Hydraulic Conductivity Aquifer (m/yr)	Unsaturated Zone Thickness (m)	Aquifer Thickness (m)	Hydraulic Gradient (m/yr)	Notes
3	158	0.914	4.57	0.003	
3	6.31	1.37	3.66	0.027	
3	9.46	2.56	2.74	0.042	
3	-7.81342	2.72776	2.93298	-4.6888	Mean
3	21.2765	2.78074	0.6463	-1.30916	Covariance
3	2.78074	1.07038	0.17468	0.29718	Covariance
3	0.6463	0.17468	0.96341	-0.64536	Covariance
3	-1.30916	0.29718	-0.64536	1.9708	Covariance
3	6.31	0.914	1.52	0.000000004	Minimum
3	25500	30.5	45.7	0.05	Maximum
4	50800	4.57	9.14	0.005	
4	13900	-999	33.5	0.028	
4	-999	6.1	-999	-999	
4	-999	12.2	4.57	0.01	
4	1580	2.13	12.2	0.001	
4	3.15	19.8	2.44	0.007	
4	12.6	4.57	10.7	0.07	
4	-999	0.914	6.1	0.043	
4	2520	1.52	3.05	0.02	
4	3150	2.44	-999	0.000002	
4	9.46	1.83	6.04	0.055	
4	94.6	0.61	3.96	0.006	
4	-999	6.98	53.3	-999	
4	116000	15.2	76.2	0.004	
4	12600	7.62	6.4	0.049	
4	4100	2.13	32	0.003	
4	-999	10.7	8.53	0.0006	
4	-999	0.61	7.62	0.001	
4	3150	0.305	9.14	0.003	
4	221	1.52	7.62	0.004	
4	-999	4.57	27.4	0.015	
4	3.15	3.05	3.05	0.02	
4	631	2.44	7.62	0.005	
4	-999	50.8	145	0.092	
4	-999	15.2	6.1	0.0000001	
4	31.5	33.5	-999	0.023	
4	315	9.14	3.05	0.002	
4	4420	1.52	19.8	0.002	
4	631	2.21	0.332	0.001	
4	-999	1.22	-999	-999	
4	-999	9.14	3.05	0.005	
4	7880	22.9	3.05	0.02	
4	5360	3.05	6.1	0.001	
4	-6.82634	2.65875	3.3063	-4.9212	Mean
4	9.60704	0.51036	1.46619	-1.4956	Covariance
4	0.51036	1.5223	-0.01024	0.0939	Covariance
4	1.46619	-0.01024	1.28413	-0.02391	Covariance

Table O-2. Correlated Empirical Distributions

Aquifer Code	Longitudinal Hydraulic Conductivity Aquifer (m/yr)	Unsaturated Zone Thickness (m)	Aquifer Thickness (m)	Hydraulic Gradient (m/yr)	Notes
4	-1.4956	0.0939	-0.02391	1.83998	Covariance
4	3.15	0.305	0.332	0.0000001	Minimum
4	116000	50.8	145	0.092	Maximum
5	5680	3.05	21.3	0.002	
5	-999	0.914	3.96	-999	
5	946	-999	15.2	0.093	
5	-999	3.05	6.1	0.01	
5	158000	6.1	3.05	0.0001	
5	63100	5.18	1.52	0.005	
5	-999	6.1	3.05	0.005	
5	15.6	38.1	1.52	0.025	
5	126000	4.57	4.57	0.001	
5	-999	4.57	22.9	0.03	
5	7570	30.5	-999	-999	
5	-999	101	15.2	0.05	
5	1580	33.5	914	0.001	
5	31500	30.5	24.4	0.001	
5	-999	9.75	15.2	-999	
5	6.31	3.38	7.62	0.003	
5	-999	32.9	4.57	-999	
5	23700	42.7	6.1	0.003	
5	-999	10.7	1.07	-999	
5	1580	19.8	24.4	0.005	
5	1260	2.44	-999	-999	
5	3150	12.2	3.81	-999	
5	126	15.2	4.57	0.002	
5	946	3.05	3.05	0.002	
5	-999	4.57	-999	-999	
5	-999	2.44	-999	-999	
5	1390	34.1	91.4	0.003	
5	-999	12.2	85.3	-999	
5	-999	3.66	-999	-999	
5	-999	27.4	-999	0.006	
5	-999	15.9	16.2	0.0004	
5	94.6	7.01	9.14	0.0003	
5	2840	42.7	30.5	0.002	
5	158	13	130	0.001	
5	-999	18.3	3.66	0.01	
5	1260	7.32	18.3	0.0001	
5	63.1	82.3	-999	-999	
5	15800	36.6	-999	0.001	
5	3470	7.62	15.2	0.02	
5	-999	12.2	15.2	0.001	
5	126	1.83	11	0.002	
5	2210	15.2	9.14	-999	
5	3.15	3.66	2.44	0.005	
5	-999	12.2	48.8	0.01	

Table O-2. Correlated Empirical Distributions

Aquifer Code	Longitudinal Hydraulic Conductivity Aquifer (m/yr)	Unsaturated Zone Thickness (m)	Aquifer Thickness (m)	Hydraulic Gradient (m/yr)	Notes
5	-999	36.6	-999	0.068	
5	63700	61	-999	-999	
5	3.15	61	15.2	0.015	
5	-999	7.01	18.3	-999	
5	631	14.6	24.4	0.003	
5	3190000	9.14	0.305	0.000002	
5	3150	10.7	3.05	0.006	
5	3.15	4.72	18.3	0.07	
5	946	13.7	6.1	0.008	
5	3150	7.62	7.62	-999	
5	315	4.88	9.14	0.017	
5	11000	2.44	6.1	-999	
5	-999	2.44	5.18	0.04	
5	-999	3.96	18.3	-999	
5	12.6	2.13	0.61	-999	
5	2210	9.14	1.52	0.025	
5	-999	3.05	6.1	0.013	
5	22100	6.1	91.4	0.001	
5	-5.61434	3.43835	3.53678	-5.61773	Mean
5	9.98295	0.28014	0.08839	-2.96927	Covariance
5	0.28014	0.8396	0.54136	0.0448	Covariance
5	0.08839	0.54136	2.05569	-0.71488	Covariance
5	2.96927	0.0448	-0.71488	4.17328	Covariance
5	3.15	0.914	0.305	0.000002	Minimum
5	3190000	101	914	0.093	Maximum
6	-999	15.2	18.3	0.005	
6	-999	1.83	9.14	0.002	
6	315	4.88	15.2	0.001	
6	631	8.53	9.14	0.01	
6	107000	3.51	7.32	0.005	
6	1890	24.4	36.6	0.001	
6	3.15	2.74	3.66	0.003	
6	-999	21.3	7.62	0.001	
6	4100	27.4	3.05	0.001	
6	16700	2.44	6.4	0.004	
6	11000	5.49	13.1	0.002	
6	315	1.52	3.05	0.002	
6	-999	1.22	1.83	0.008	
6	11000	5.79	-999	0.0005	
6	-999	3.96	4.27	0.017	
6	-999	12.2	16.8	0.002	
6	1580	4.57	7.62	0.04	
6	33100	30.5	22.9	0.01	
6	-999	4.57	7.62	0.1	
6	252	11.5	-999	0.005	
6	14200	4.57	18.3	0.0007	
6	3150	1.52	1.52	0.0000004	

Table O-2. Correlated Empirical Distributions

Aquifer Code	Longitudinal Hydraulic Conductivity Aquifer (m/yr)	Unsaturated Zone Thickness (m)	Aquifer Thickness (m)	Hydraulic Gradient (m/yr)	Notes
6	5680	3.05	6.1	0.001	
6	1890	3.66	6.1	0.002	
6	315	3.66	0.61	0.000001	
6	31.5	1.52	-999	0.00000002	
6	3150	1.19	3.66	-999	
6	15500	5.18	7.93	0.006	
6	5520	3.66	5.49	0.01	
6	3150	3.05	16.8	0.013	
6	158	1.52	3.05	0.012	
6	22.1	1.22	13.7	0.004	
6	-999	1.83	9.14	0.011	
6	9.46	0.914	6.1	0.008	
6	-999	10.7	15.2	0.00008	
6	-999	12.2	12.2	0.000001	
6	-6.7624	2.65846	3.15814	-5.6184	Mean
6	13.8058	1.67704	2.14642	-0.09303	Covariance
6	1.67704	0.8987	0.34951	-0.23716	Covariance
6	2.14642	0.34951	0.86919	0.00252	Covariance
6	-0.09303	-0.23716	0.00252	1.23921	Covariance
6	3.15	0.914	0.61	0.00000002	Minimum
6	107000	30.5	36.6	0.1	Maximum
7	946	2.44	8.23	0.002	
7	1260	2.13	305	0.003	
7	-999	35.4	-999	-999	
7	6940	-999	22.9	0.003	
7	23300	15.2	36.6	0.004	
7	4420	1.83	38.1	0.0007	
7	56100	3.05	10.1	0.002	
7	55200	3.05	61	-999	
7	9460	57.9	9.14	0.000001	
7	-999	9.14	9.14	0.0002	
7	-999	12.2	9.14	0.002	
7	946	3.05	3.05	0.008	
7	9780	3.05	3.05	0.013	
7	-999	5.18	12.2	0.002	
7	4420	3.66	15.2	0.005	
7	4420	24.4	21.3	0.01	
7	1580	1.52	24.4	0.01	
7	82000	14.9	8.53	0.003	
7	946	12.2	18.3	0.000002	
7	11000	3.05	4.57	-999	
7	-999	4.57	13.7	0.01	
7	6940	2.13	7.99	0.004	
7	6310	7.01	5.18	0.049	
7	23700	4.88	18.3	0.033	
7	17700	5.79	42.7	0.002	
7	1890	4.57	10.7	0.000004	

Table O-2. Correlated Empirical Distributions

Aquifer Code	Longitudinal Hydraulic Conductivity Aquifer (m/yr)	Unsaturated Zone Thickness (m)	Aquifer Thickness (m)	Hydraulic Gradient (m/yr)	Notes
7	14500	1.52	18.3	0.012	
7	120000	22	-999	0.01	
7	2520	1.52	6.1	0.011	
7	12.6	5.79	4.27	0.021	
7	315	0.61	4.57	0.006	
7	31.5	0.457	-999	0.001	
7	-999	45.7	3.05	-999	
7	-5.22204	2.81441	3.78819	-5.30668	Mean
7	13.0649	-1.10808	0.50353	-0.73884	Covariance
7	-1.10808	1.13841	0.0496	0.26902	Covariance
7	0.50353	0.0496	1.11517	-0.46202	Covariance
7	-0.73884	0.26902	-0.46202	1.11713	Covariance
7	12.6	0.457	3.05	0.000001	Minimum
7	120000	57.9	305	0.049	Maximum
8	6310	7.62	61	0.001	
8	24000	4.88	22.9	0.002	
8	30000	2.99	18.9	0.004	
8	-999	12.2	6.71	0.001	
8	2520	3.05	21.3	0.0000008	
8	110000	9.14	21.3	0.004	
8	13300	5.49	12.2	0.006	
8	37800	4.57	9.14	0.003	
8	1260	10.7	-999	0.008	
8	2210	3.05	22.9	0.0009	
8	9780	3.35	15.2	0.0007	
8	1890	48.8	32	0.03	
8	34400	7.62	26.2	0.006	
8	44200	4.88	18.6	0.002	
8	15800	29	24.4	0.001	
8	7250	9.14	39.6	0.0006	
8	13900	12.2	122	0.002	
8	29000	2.74	10.1	-999	
8	99700	2.13	7.01	0.0007	
8	-999	4.57	6.1	0.003	
8	14800	1.83	61	0.001	
8	7880	2.44	3.05	0.03	
8	-999	15.2	76.2	0.0009	
8	5680	2.44	6.1	0.001	
8	18900	4.57	7.62	0.005	
8	3880	3.66	7.62	0.004	
8	-999	22	18.3	0.0006	
8	473	6.1	4.57	0.017	
8	10400	7.62	30.5	0.001	
8	22100	9.14	7.62	0.005	
8	27800	7.62	24.4	0.002	
8	27800	7.62	24.4	0.002	
8	-999	6.1	4.57	0.00004	

Table O-2. Correlated Empirical Distributions

Aquifer Code	Longitudinal Hydraulic Conductivity Aquifer (m/yr)	Unsaturated Zone Thickness (m)	Aquifer Thickness (m)	Hydraulic Gradient (m/yr)	Notes
8	11000	12.2	3.05	0.075	
8	19200	5.33	12.2	0.008	
8	631	0.914	10.7	0.01	
8	19200	18.3	10.7	0.013	
8	5050	0.61	12.2	0.003	
8	-999	7.62	30.5	0.002	
8	33100	15.2	30.5	0.0004	
8	-999	4.57	22.9	0.01	
8	2210	2.13	3.66	0.02	
8	60900	20	30.5	0.003	
8	-3.59646	2.97372	3.92385	-5.86511	Mean
8	5.02	0.48626	0.15471	-0.8019	Covariance
8	0.4862	0.85551	0.26963	0.07004	Covariance
8	0.1547	0.26963	0.75329	-0.62236	Covariance
8	-0.8019	0.07004	-0.62236	1.62199	Covariance
8	473	0.61	3.05	0.0000008	Minimum
8	110000	48.8	122	0.075	Maximum
9	946	2.1	13.7	0.05	
9	315	13.7	12.2	0.001	
9	18.9	3.66	5.49	0.008	
9	21800	6.1	15.2	0.004	
9	3470	39.6	54.9	0.017	
9	3150	21.3	4.57	0.01	
9	126	1	30	-999	
9	31.5	7.62	3.05	0.009	
9	-999	3.05	30.5	0.0000005	
9	31.5	5.18	10.7	0.03	
9	315	3.96	22.9	0.007	
9	63.1	4.57	2.96	0.022	
9	915	2.44	12.2	0.0007	
9	-999	7.32	12.2	-999	
9	1890	1.83	0.914	0.005	
9	3150	7.62	7.62	-999	
9	631	3.66	2.13	-999	
9	6310	2.44	9.14	0.00000004	
9	-999	2.13	7.62	0.009	
9	4100	1.52	6.1	0.01	
9	126	3.05	4.57	0.05	
9	126	3.05	7.62	0.02	
9	-999	0.61	1.83	-999	
9	12.6	1.83	-999	0.04	
9	8830	1.52	18.3	0.004	
9	315	1.52	6.1	-999	
9	284	1.74	9.14	0.01	
9	9.46	18.3	2.44	0.003	
9	1580	3.35	6.1	0.000004	
9	-7.67984	2.48552	3.22796	-4.68545	Mean

Table O-2. Correlated Empirical Distributions

Aquifer Code	Longitudinal Hydraulic Conductivity Aquifer (m/yr)	Unsaturated Zone Thickness (m)	Aquifer Thickness (m)	Hydraulic Gradient (m/yr)	Notes
9	11.259	0.17085	0.72472	-0.72109	Covariance
9	0.17085	0.87319	0.13478	-0.12094	Covariance
9	0.72472	0.13478	0.81983	-0.0043	Covariance
9	-0.72109	-0.12094	-0.0043	1.28625	Covariance
9	9.46	0.61	0.914	0.00000004	Minimum
9	21800	39.6	54.9	0.05	Maximum
10	-999	3.35	14.6	0.03	
10	4420	11.6	54.9	0.005	
10	284	4.57	7.62	0.01	
10	19600	39.6	21.4	0.0003	
10	158	4.57	3.05	0.0006	
10	315	1.52	6.1	0.004	
10	-999	6.1	3.66	0.000001	
10	126	7.62	2.29	0.005	
10	315	15.2	10.7	0.01	
10	31.5	2.74	6.86	0.017	
10	126	3.05	4.12	0.003	
10	-999	3.81	6.1	0.00001	
10	-999	3.66	15.2	0.1	
10	631	4.57	0.914	0.005	
10	3470	3.05	3.05	0.002	
10	2210	25.9	7.62	0.00001	
10	-999	1.52	15.2	0.002	
10	2840	2.74	4.57	-999	
10	-999	1.83	2.44	0.008	
10	2210	13.7	7.62	0.01	
10	126	12.2	12.2	0.025	
10	-999	3.81	16.8	0.002	
10	-999	3.32	1.83	0.06	
10	3.15	3.66	11.6	0.01	
10	25.2	1.83	4.57	0.0095	
10	4420	10.7	9.14	0.014	
10	-999	6.1	42.7	0.00175	
10	-6.97635	2.80942	3.15655	-5.57335	Mean
10	4.99889	1.27993	0.51266	-1.74813	Covariance
10	1.27993	0.86035	0.40799	-0.71454	Covariance
10	0.51266	0.40799	0.8467	0.03369	Covariance
10	-1.74813	-0.71454	0.03369	3.61694	Covariance
10	3.15	1.52	0.914	0.000001	Minimum
10	19600	39.6	54.9	0.1	Maximum
11	946	2.13	305	0.01	
11	63.1	2.74	30.5	0.03	
11	7250	9.14	36.6	0.0006	
11	24300	4.57	10.7	0.0068	
11	-999	1.52	305	0.001	
11	7570	3.05	45.7	0.006	
11	12600	0.914	4.57	0.005	

Table O-2. Correlated Empirical Distributions

Aquifer Code	Longitudinal Hydraulic Conductivity Aquifer (m/yr)	Unsaturated Zone Thickness (m)	Aquifer Thickness (m)	Hydraulic Gradient (m/yr)	Notes
11	631	0.914	6.1	0.01	
11	3150	1.52	6.1	-999	
11	1260	1.22	10.7	0.002	
11	31.5	0.914	15.2	0.005	
11	13900	1.52	61	0.002	
11	-999	1.68	15.2	0.002	
11	2520	2	2	0.002	
11	1260	1.22	3.05	0.017	
11	-999	0.914	7.62	-999	
11	315	1.52	1.52	0.05	
11	1580	2.74	4.57	0.023	
11	-999	3.35	4.27	0.019	
11	315	3.05	24.4	0.001	
11	284	1.07	30.5	0.003	
11	946	2.13	1.68	0.0002	
11	-999	2.74	21.3	0.00003	
11	8170	7.01	6.1	0.0033	
11	-999	-999	6.71	-999	
11	-999	3.05	42.7	0.0005	
11	-5.38023	1.8991	3.7492	-5.61773	Mean
11	3.48349	0.52513	-0.00422	-0.63963	Covariance
11	0.52513	0.46903	0.18069	-0.2284	Covariance
11	-0.00429	0.18069	2.02612	-0.08327	Covariance
11	-0.63963	-0.2284	-0.08327	1.97797	Covariance
11	31.5	0.914	1.52	0.00003	Minimum
11	24300	9.14	305	0.05	Maximum
12	158000	30	30	0.006	
12	-999	50	10	0.005	
12	1580	50.8	144	0.023	
12	-999	15.2	91.4	-999	
12	-999	3.05	-999	0.012	
12	1580	45.7	-999	-999	
12	126	3.05	15.2	0.00005	
12	315	12.2	61	0.033	
12	-999	30.5	-999	0.02	
12	-999	320	-999	0.009	
12	-999	5.33	15.2	0.001	
12	15800	29.3	19.5	-999	
12	-999	18.3	-999	-999	
12	221	-999	39.6	0.002	
12	315	3.96	3.05	0.018	
12	24900	1.52	-999	0.002	
12	12300	3.96	18.3	0.009	
12	-999	3.05	305	0.001	
12	94.6	7.62	19.8	0.01	
12	1260	400	18	0.000002	
12	2180	1.68	7.32	0.00042	

Table O-2. Correlated Empirical Distributions

Aquifer Code	Longitudinal Hydraulic Conductivity Aquifer (m/yr)	Unsaturated Zone Thickness (m)	Aquifer Thickness (m)	Hydraulic Gradient (m/yr)	Notes
12	6310	1.22	3.05	-999	
12	-5.6496	3.47765	4.32063	-5.49537	Mean
12	12.0503	1.43257	0.53279	0.79733	Covariance
12	1.43257	1.25667	0.99541	1.35511	Covariance
12	0.53279	0.99541	1.2437	0.81321	Covariance
12	0.79733	1.35511	0.81132	4.45451	Covariance
12	94.6	1.22	3.05	0.000002	Minimum
12	158000	400	305	0.033	Maximum
13	1890	5.18	10.1	0.0057	
13	-5.6496	3.47765	4.32063	-5.49537	Mean
13	12.0503	1.43257	0.53279	0.79733	Covariance
13	1.43257	1.25667	0.99541	1.35511	Covariance
13	0.53279	0.99541	1.2437	0.81321	Covariance
13	0.79733	1.35511	0.81132	4.45451	Covariance
13	3.15	0.305	0.305	0.000000004	Minimum
13	22100000	610	914	1	Maximum

References:

Newell et al., 1989

U.S. EPA, 1997a

U.S. EPA, 1997b

Table O-3. Empirical Distributions for Groundwater Modeling

VariableID	Parameter	Units	Value	CDF
ALPHA(AL)	Longitudinal dispersivity (aquifer)	m	0.1	0
			1	0.1
			10	0.7
			100	1
DIAM	Avg. particle diameter	cm	0.00039	0
			0.00078	0.038
			0.0016	0.104
			0.0031	0.171
			0.0063	0.262
			0.0125	0.371
			0.025	0.56
			0.05	0.792
	Avg. Particle Dameter		0.1	0.904
	Avg. particle diameter		0.2	0.944
			0.4	0.976
			0.8	1
RADIS(I)	Radial distance to well (R)	m	0.6	0
			13.7	0.03
			19.8	0.04
			45.7	0.05
			103.6	0.1
			152.4	0.15
			182.9	0.2
			243.8	0.25
			304.8	0.3
			304.8	0.35
			365.7	0.4
			396.2	0.45
			426.7	0.5
			457.2	0.55
			609.6	0.6
			762	0.65
			804.6	0.7
			868.6	0.75
			914.4	0.8
			1158.2	0.85
			1219.1	0.9
			1371.5	0.95
			1523.9	0.98
			1609.3	1

CDF = Cumulative distribution functio

References:

Gelhar et al., 1992

U.S. EPA, 1997a

Table O-4. Organic Constituent Surrogate Groups

Name	CAS #	Koc	KOC Group	Lambda	Lambda Group
Ethylene glycol	**107-21-1**	**3.02E-02**	**2**	**0**	**1**
Methanol	67-56-1	8.32E-02	2	0	1
Formaldehyde	50-00-0	4.27E-01	2	0	1
Methyl ethyl ketone (mek)	78-93-3	9.33E-01	2	0	1
Vinyl acetate	108-05-4	2.57E+00	2	0	1
n-Butyl alcohol	71-36-3	3.18E+00	2	0	1
Methyl isobutyl ketone (mibk)	108-10-1	7.41E+00	2	0	1
Phenol	108-95-2	1.70E+01	2	0	1
Chloroform	**67-66-3**	**3.80E+01**	**2**	**7.46E-05**	**2**
Acrylonitrile	**107-13-1**	**8.15E-01**	**2**	**0.000118**	**3**
Methyl methacrylate	80-62-6	5.50E+00	2	0.034277	3
Dichloromethane (methylene chloride)	75-09-2	8.51E+00	2	0.00029	3
Tetrachloroethylene	**127-18-4**	**1.62E+02**	**3**	**0**	**1**
2,4-dimethylphenol	105-67-9	1.95E+02	3	0	1
Toluene	108-88-3	2.69E+02	3	0	1
Styrene	100-42-5	6.92E+02	3	0	1
Pentachlorophenol	**87-86-5**	**1.15E+03**	**4**	**0**	**1**
Ethylbenzene	**100-41-4**	**1.00E+03**	**4**	**0**	**1**
o-Xylene	95-47-6	1.05E+03	4	0	1
m-Xylene	108-38-3	1.05E+03	4	0	1
xylene (mixed isomers)	1330-20-7	1.20E+03	4	0	1
p-xylene	106-42-3	1.32E+03	4	0	1
Dibutylphthalate	**84-74-2**	**2.34E+04**	**5**	**3.47E-05**	**2**
Di(2-ethylhexylphthalate)	117-81-7	1.35E+07	5	7.15E-10	2

Note: The constituents in bold are the chemicals that were modeled for the groundwater pathway.

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Appendix P

Shower Model

Appendix P

Shower Model

Exposure to contaminants in groundwater through noningestion pathways (i.e., showering) was modeled using an indoor inhalation exposure model. For the noningestion pathway modeling, the modeled groundwater concentration for each constituent of concern was used as the starting concentration, and inhalation risks were estimated based on this starting concentration.

The model used in this analysis is based on the equations presented in McKone (1987). The model estimates the change in the shower air concentration based on the mass of constituent lost by the water (fraction emitted or emission rate) and the air exchange rate between the various model compartments (shower, the rest of the bathroom, and the rest of the house) following the same basic model construct described by Little (1992). The resulting differential equations are solved using finite difference numerical integration.

The basis for estimating the concentration of constituents in the indoor air is the mass transfer of constituent from water to shower air. This equation estimates the overall mass transfer coefficient from tap water to air from showering:

$$K_{ol} = \beta \times \left(\frac{2.5}{D_w^{2/3}} + \frac{1}{D_a^{2/3} H'} \right)^{-1} \qquad \text{(P-1)}$$

where

K_{ol} = overall mass transfer coefficient (cm/s)
β = proportionality constant $(cm/s)^{-1/3}$
D_w = diffusion coefficient in water (cm^2/s)
D_a = diffusion coefficient in air (cm^2/s)
H' = dimensionless Henry's law constant ($=41*H_{LC}$).

The constituent emission rate is estimated from the change in the shower water concentration as the water falls, which is calculated using the overall mass transfer coefficient as follows:

$$\delta c/\delta t = -K_{ol}(A/V)(c - y_s/H') \quad \text{(P-2)}$$

where

c	=	liquid phase (droplet) constituent concentration (µg/cm^3 or mg/L)
t	=	time (s)
A	=	total surface area for mass transfer (cm^2)
V	=	total volume of water within the shower compartment (cm^3)
y_s	=	gas phase constituent concentration in the shower (µg/cm^3 or mg/L)
H´	=	dimensionless Henry's law constant.

Consequently, in addition to the overall mass transfer coefficient, the emission rate of a contaminant within the shower is dependent on the surface-area-to-volume ratio of the shower water (within the shower) and the concentration differential between the water and the shower air.

The shower emissions can be modeled based on falling droplets as a means of estimating the surface-area-to-volume ratio for mass transfer and the residence time of the water in the shower compartment. Equation P-2 can then be integrated assuming the compound concentration in the gas phase is constant over the time frame of the droplet fall. The time required for a droplet to fall equals the nozzle height divided by the water droplet velocity. The ratio of the surface area to volume for the droplet is calculated as $6/d_p$ (i.e., by assuming a spherical shape). By assuming the drops fall at terminal velocity, the surface-area-to-volume ratio and the residence time can be determined based solely on droplet size. A droplet size of approximately 1 mm (0.1 cm) was selected. The terminal velocity for the selected droplet size is approximately 400 cm/s. The fraction of constituent emitted from a water droplet at any given time can then be calculated by integrating Equation P-2 and rearranging as follows:

$$f_{em} = 1 - c_{out}/c_{in} = (1 - f_{sat})(1 - e^{-N}) \quad \text{(P-3)}$$

where

f_{em}	=	fraction of constituent emitted from the droplet (dimensionless)
c_{out}	=	droplet constituent concentration at shower floor/drain (mg/L)
c_{in}	=	droplet constituent concentration entering the shower (mg/L)
f_{sat}	=	$y_s/(H' c_{in})$ = fraction of gas phase saturation (dimensionless)
N	=	dimensionless overall mass transfer coefficient = $K_{ol}\,(6/d_p)\,(h/v_t)$
d_p	=	droplet diameter (cm)
h	=	nozzle height (cm)
v_t	=	terminal velocity of droplet (cm/s).

The gas phase constituent concentration in the shower is then calculated for each time step for the duration of the shower. The air exchange rate between the shower and the bathroom is included in the estimation of the gas phase concentration of the constituents in the shower:

$$y_{s,t+1} = y_{s,t} + [Q_{gs} \times (y_{b,t} - y_{s,t}) \times (t_{t+1} - t_t) + E_{s,t}]/V_s \qquad \text{(P-4)}$$

where

$y_{s,t+1}$	=	gas phase constituent concentration in the shower at the end of time step (mg/L)
$y_{s,t}$	=	gas phase constituent concentration in the shower at the beginning of time step (mg/L)
Q_{gs}	=	volumetric gas exchange rate between shower and bathroom (L/min)
$y_{b,t}$	=	gas phase constituent concentration in the bathroom at the beginning of time step (mg/L)
$(t_{t+1}-t_t)$	=	calculation time step (min)
$E_{s,t}$	=	mass of constituent emitted from shower between time t and time t+1 (mg)
V_s	=	volume of shower stall (L).

The gas phase constituent concentration in the bathroom may be estimated by the following equation for each time step of the exposure duration:

$$y_{b,t+1} = y_{b,t} + \{[Q_{gs} \times (y_{s,t} - y_{b,t})] - [Q_{gb} \times (y_{b,t} - y_{h,t})] + (I_b \times C_{in} \times f_{em,b})\} \times \left(\frac{t_{t+1} - t_t}{V_b} \right) \qquad \text{(P-5)}$$

where

$y_{b,t+1}$	=	gas phase constituent concentration in the bathroom at end of time step (mg/L)
$y_{b,t}$	=	gas phase constituent concentration in the bathroom at beginning of time step (mg/L)
Q_{gs}	=	volumetric gas exchange rate between shower and the bathroom (L/min)
$y_{s,t}$	=	gas phase constituent concentration in the shower at the beginning of time step (mg/L)
Q_{gb}	=	volumetric gas exchange rate between the bathroom and house (L/min)
I_b	=	bathroom water use (L/d)

C_{in} = constituent concentration in tap water (mg/L)

$f_{em,b}$ = fraction of constituent emitted from bathroom water use (unitless) (see Equation P-6)

V_b = volume of bathroom (L)

$y_{h,t}$ = gas phase constituent concentration in the house at beginning of time step (mg/L)

$(t_{t+1} - t_t)$ = calculation time step (min).

The average air concentration in the shower and bathroom are obtained by averaging the concentrations obtained for each time step over the duration of the shower and bathroom use. These concentrations and the durations of daily exposure and are used to estimate risk from inhalation exposures to residential use of groundwater.

The fraction emitted from the bathroom or household water use is a function of the input transfer efficiency (or maximum fraction emitted) and the driving force for mass transfer. For the bathroom, the fraction emitted is calculated as follows:

$$f_{em,b} = \left(1 - \frac{y_b}{H' \; C_w}\right)(\varepsilon_{transfer} \; f_{max,b}) \qquad \text{(P-6)}$$

where

$f_{em,b}$ = fraction of constituent emitted from bathroom water use (unitless)

y_b = gas phase constituent concentration in the bathroom (mg/L)

H' = dimensionless Henry's law constant (=41*H_{LC}).

C_w = constituent concentration in tap water (mg/L)

$\varepsilon_{transfer}$ = transfer efficiency for nonshower water use (unitless) (see Equation P-7)

$f_{max,b}$ = maximum transfer efficiency for bathroom water use (unitless).

The transfer efficiency is calculated using the following equation based on Little (1992).

$$\varepsilon_{transfer} = 2.76E{+}6 \left(\frac{2.5}{(D_l \times 10^{-4})^{0.667}} + \frac{70}{(D_a \times 10^{-4})^{0.667} \times H'}\right)^{-1} \qquad \text{(P-7)}$$

where

$\varepsilon_{transfer}$	=	transfer efficiency for nonshower water use (unitless)
D_l	=	diffusion coefficient in water (cm^2/s)
D_a	=	diffusion coefficient in air (cm^2/s)
H'	=	dimensionless Henry's law constant ($=41*H_{LC}$).

Table P-1 presents the shower model input parameters and the values used in the paints listing risk analysis.

Table P-1. Shower Model Input Parameter Used in Paints Listing Risk Analysis

Parameter	Value	Reference
Shower duration	16.7 min (population-estimated mean, varied in probabilistic analysis)	U.S. EPA, 1997 (EFH table 15-21)
Time spent in shower after showering	5 min	U.S. EPA, 1997 (EFH table 15-23)
Shower rate	5.5 L/min	calculated (based on droplet diameter and nozzle velocity)
Shower volume	2.0 m^3	McKone, 1987
Bathroom volume	10.0 m^3	McKone, 1987
House volume	369 m^3	U.S. EPA, 1997 (EFH table 17-31)
Shower vent rate	100 L/min	RTI-derived value
Bathroom vent rate	300 L/min	RTI-derived value
Bathroom water use	35.5 gal/d (134 L/d)	U.S. EPA, 1997 (EFH table 17-14)
Fem, bathroom	0.50	Calculated
Water droplet diameter	0.098 cm	RTI-derived value
Nozzle velocity	400 cm/s	RTI-derived value
Nozzle height	1.8 m	RTI-derived value

References

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